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Brunswick Mining & Smelting Corporation Limited
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United States Bureau of Mines
United States Environmental Protection Agency
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Geological Survey of Canada
Metal Mining Agency of Japan
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U.S. Geological Survey
University of Waterloo
University of Western Ontario

MEND (Mine Environment Neutral Drainage) is a cooperative research program sponsored, financed and administered by 3 partners; the Canadian mining industry, the Government of Canada and the Governments of the provinces of British Columbia, Manitoba, Ontario, Quebec, New Brunswick, Saskatchewan, Nova Scotia and Newfoundland.

The objectives of MEND are to:

- establish techniques that will enable the operation and closure of acid-generating tailings and waste rock disposal areas in a **predictable, timely, affordable,** and **environmentally acceptable** manner.

- provide a comprehensive, scientific, technical and economic basis for the mining industry and government agencies, to predict with confidence the long term management requirements for reactive tailings and waste rock; and

Four committees direct and manage the technical components of the program: Prediction and Monitoring, Prevention & Control, Treatment and Technology Transfer. These committees have specific mandates to develop techniques that reduce the environmental impact and financial liabilities caused by acidic drainage. A Management committee is responsible for managing the overall program and a Board of Directors reviews and approves budgets and program direction. The MEND Secretariat coordinates the activities of the committees and their respective programs. Participation in MEND is on a volunteer basis. Committee members contribute their time and expertise without financial compensation from MEND.

MEND is a 9-year program, scheduled for completion in December 1997. The research program was redefined in 1992 and is outlined in the **Revised Research Plan, 1992**. The results of MEND are being made widely distributed through reports, publications, seminars, workshops and via the MEND Internet site ***(http://www.NRCan.gc.ca/mets/mend***.

NEDEM (Neutralisation des Eaux de Drainage dans l'Environnement Minier) est un programme de recherche qui est parrainé, financé et administré conjointement par 3 partenaires; l'industrie minière canadienne, le gouvernement fédéral et les gouvernements de la Colombie-Britannique, du Manitoba, de l'Ontario, du Québec, du Nouveau-Brunswick, de la Saskatchewan, de la Nouvelle-Écosse et de Terre Neuve.

Les objectifs du NEDEM sont les suivants:

- établir les fondements scientifiques, techniques et économiques permettant à l'industrie minière et aux organismes gouvernementaux de prédire avec confiance les besoins à long terme en matière de gestion des résidus réactifs et des stériles, et

- mettre au point des techniques permettant l'exploitation et l'abandon, de manière **prévisible, économique opportune et acceptable pour l'environnement**, des aires d'élimination de résidus miniers acides et des stériles.

Le programme est composé de 4 comités techniques: Prévision et Surveillance, Prévention et contrôle , Traitement et Transfert de la technologie. Ces comités ont des mandats spécifiques afin d'explorer les différentes voies permettant de réduire l'impact environnemental du drainage acide ainsi que l'engagement financier qu'il représente. Le comité de gestion est responsable de gérer le programme général et le conseil d'administration révisent et approuvent les budgets et la direction générale du programme. Le secrétariat NEDEM coordonne les comités techniques et leurs programmes respectifs. La participation au programme ce fait sur une base volontaire. Les membres des comités fournissent temps et expertise sans contribution financière de la part du NEDEM

NEDEM est un programme de 9 ans qui devrait être complété en décembre 1997. La direction du programme a été redéfinie en 1992 et est présenté dans le **Plan de recherche révisé 1992**. Les résultats du programme NEDEM sont publiés dans des rapports et des publications, et son également présentés à l'occasion de séminaires, d'ateliers et par le biais d'Internet ***(http://www.NRCan.gc.ca/mets/mend)***.

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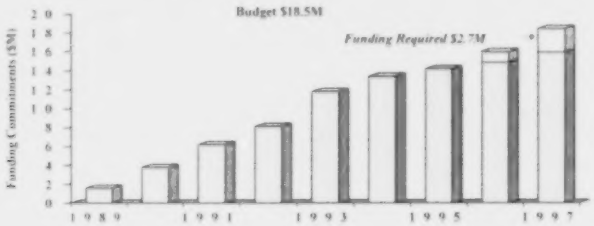
TECHNICAL SUMMARY

MEND has completed 7 years of technology development for prediction, prevention, and control of acidic drainage from mine wastes and mine openings. During 1995, the MEND committees continued their principal tasks of directing the research and development, and of reporting the results in a user-friendly way. MEND has made a major contribution in reducing the $3 to $5 billion liability associated with acidic drainage in Canada; and is dedicated to completing the agreed upon program of work within the budget and time approved by the MEND Board of Directors.

In the final years of the MEND program, the emphasis will continue to be placed on completing approved projects, and on technology transfer. MEND will continue to host several workshops across Canada and culminating with the **4th International Conference on Acid Rock Drainage** in Vancouver in 1997.

As shown in Figure 1, MEND is approaching its target to remain within the budgetary ceiling of $18.5 million approved in April 1995.

Figure 1: Profile of MEND Expenditures 1989 - 1997



In 1995, the **Prediction** and **Monitoring committees** were combined under the co-chairs Mr. Bill Napier and Dr. Ed Kustan. The **Prediction committee** had earlier dropped the ambitious theoretical waste rock model development program in favour of the empirical approach, that is, to use and analyze data from actual sites to develop simple protocols for prediction of acid generation in rock piles. This approach is resulting in simpler methods to analyze options for management of acid-generating waste rock, be it managed in situ or returned to the mine. Studies completed at Mine Doyon provided an excellent data base on waste rock, and these data have been subject to detailed analyses. A detailed field study for another type of waste rock started in 1995 at the Whistle mine site and along with international information, it will compliment the Doyon data.

Prediction/Monitoring has made progress in improving and documenting the chemical methods for determining the potential and rate of acid generation in mine wastes. Also, in cooperation with the Prevention and Control committee, a program is underway to evaluate the potential for engineering a permafrost environment to prevent and/or control acidic drainage at mine sites in northern

Canada. Results to date indicate that experimental data is needed to supplement anecdotal information.

The final **Monitoring** project, the monitoring manual, will be completed in May 1996 and will be presented and reviewed at the workshop in Saskatoon in June.

In 1995, considerable progress was realized and many significant results were generated in the **Prevention and Control** program. Underwater disposal and water covers continue to be the "flagship" projects of MEND and very promising results continue to be demonstrated. The results conclude that:

- water is a key element in the prevention of acid generation - in underwater and pit disposal, in providing an oxygen barrier in "dry covers" and in oxygen-limiting elevated water tables; and

- water covers over partially **oxidized** tailings and waste rock are also attractive, but short term measures may need to be taken, such as the use of inexpensive surface diffusion layers and alkaline mineral addition, to prevent contamination of the water column until the establishment of a surface diffusion barrier.

MEND sponsored water covers technology continues to be demonstrated in the field. Three uranium mine tailings sites in the Elliot Lake are being closed out using water covers. MEND projects were instrumental in confirming the closure technology. At the Solbec Cupra base metal tailings site in the eastern townships of Québec, the property owner utilized MEND research results, and an economic comparison, to make the decision to flood the surface of the tailings. Site monitoring is now underway. The Louvicourt copper-zinc mine opened in northwest Québec with underwater disposal of tailings in a man-made lake, and a monitoring program has been initiated at the field site and in the laboratory. The purpose of this duplication is to provide economical evaluation tools for future mines using underwater disposal. Water covers testing and evaluation methods continue to be refined under MEND to give both regulators and property owners confidence in the results.

Physical and geochemical parameters are being examined for the development of design guidelines for both shallow water covers and underwater disposal, a major output of the program.

Work continues in both the laboratory and in the field on organic reductive covers, multi-zone covers built with tailings and depyritized tailings as covers. All three technologies have shown promise at specific sites. Both the work on dry soil covers and non soil covers are under "Peer Review" and the results will be presented at the MEND workshop on dry covers in Sudbury in April 1996.

In **Treatment,** the work on passive treatment systems has been completed with a contractor's report, in manual format, on the applicability in Canada of passive treatment systems. During the balance of the MEND program, the project focus will be the stability and disposal of lime treatment sludges. Work in 1995 was focused on sludge characterization & stabilization.

Technology Transfer activities were significantly expanded during 1994 and 1995 and this will continue up to and possibly beyond the end of the program. MEND also has an Internet site (http://www.NRCan.gc.ca/mets/mend) for on-line retrieval of annual reports and summaries of MEND documents and other related information. Workshops based on MEND project results were presented at four locations across Canada, and several more will be given in 1996. These Technology Transfer workshops, which have been presented free of charge, have been an outstanding success, and are being used to fine-tune remaining MEND programs and prepare "short courses" for the 1997 conference.

A "MEND Manual" is being prepared. This manual, to be ultimately prepared in both English and French, will summarize all of the MEND and MEND associated work on acidic drainage from mine wastes and openings. Scheduled completion is December 1998, one year after the MEND program ends.

International interest in the results of the Canadian MEND program remains strong and the network of contacts in foreign countries continues to expand, particularly in South America and the far east. Several companies and organizations have expressed interest in participating in MEND as associate members, and these relationships will continue to increase in 1996. Several foreign organizations commend the successful partnership between governments and industry that MEND has demonstrated.

MEND ORGANIZATION

In 1995, steps were taken to streamline committee operations. This was needed because much of the planned work in two committees has been completed. The Prediction and Monitoring committees held their first joint meeting in June, and the Treatment committee decided to wrap up in June 1997. International Liaison is now part of the Technology Transfer function.

In times of government expenditure restraint for science and technology initiatives, valuable MEND partners have been significantly affected. As a result of the decision to close the United States Bureau of Mines in 1995, several active, and widely respected committee members were lost. Their contribution has been very much appreciated. However, in Canada, it should be noted that all provincial and federal MEND members, in spite of budget and personnel cuts and new priorities, continued to be active supporters of MEND. This continued support is acknowledged and greatly appreciated.

CANMET, with the financial support of the Mining Association of Canada, will continue to provide the required level of support for the MEND Secretariat until 1997.

It should also be noted that industrial support remains strong for MEND. Committee membership has been frequently renewed in 1995 by new, enthusiastic participants.

FINANCIAL REPORT

The financial commitment to MEND by its three partners, the Canadian mining industry, the Government of Canada, and the Provinces remained strong. Up to December 1995, $15.1 million was spent and committed on 160 MEND sponsored research projects as shown in Table 1.

Table 1: Contributions to MEND 1988 to 1995 inclusive ($000's)

	Spent (%) Completed & Active Projects	Committed (Active Projects)	Total (%)
Mining Industry	5,531 (39.8)	359	5,890 (39.0)
Canada	4,936 (35.5)	646	5,582 (36.9)
Provinces	3,427 (24.7)	221	3,648 (24.1)
TOTALS	**13,894** (100.0)	**1,226**	**15,120** (100.0)

In 1995, the Management committee directed the technical committees to prioritize all remaining projects, examine technical priorities and estimate the budget needed to complete the MEND program. These estimates are shown in Table 2 below.

Table 2: February 1996 Priority Setting to complete the MEND program ($000's)

Technical Committee	Approved, Need Funding	High Priority	edium Priority
iction/Monitoring	300	480	775
ention & Control	335	505	100
tment	60	150	
nology Transfer	59	100	
ALS	754	**1,235**	875
ulative)	(754)	**(1,989)**	(2,864)

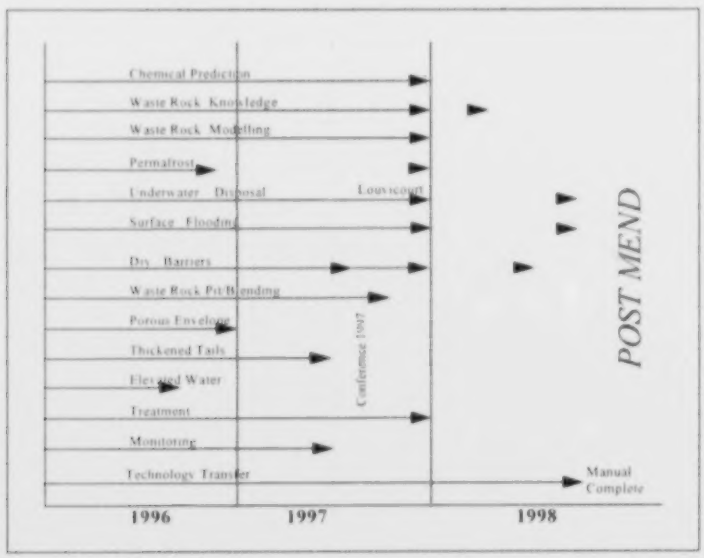
Tables 3 and 4 list the completed and active MEND projects as of the end of 1995. Table 5 lists projects which are submitted to the Board for approval. These projects will cost $1,390k, for which $776k has been committed by the funding partners. The approved budget ($18,468k) and the approved expenditure ($16,078k) on MEND projects are compared by technical committee in Table 6. It also summarizes the budgets associated with the projects proposed for approval in 1996 ($1,390k) which would bring the total program commitments to $17,468k.

Funding commitments to date are $15,120k for approved projects plus $614k for proposed projects for a total of $15,734k. **To complete the MEND program, 2,734k in new funding will need to be found.**

The estimated time profiled for completion of the key elements is shown in Figure 2. Given previous years' funding availability, MEND should be able to meet the approved and high priority project financial needs. However, with cuts in all government programs, MEND may require an even larger than normal commitment from the mining industry.

Some overlap into 1998 for technology transfer and monitoring of dry and wet covers will be required. Another cause for the program to not be completed on time may be the lack of funding for generic-type projects - e.g. generation of design guidelines.

Figure 2: Estimated Completion Dates for MEND Research Areas



As illustrated in Table 6, the technical committees have committed a high proportion of their budgets. As in past years, the overall funding commitment to the MEND program will remain an issue for the Board of Directors to address. The reality of the current economic climate in Canada must be balanced with the need to reduce potential long term environmental liability to industry and governments. Also, the Board may wish to consider options for follow-up to, or continuation of the MEND program. Several options will be presented at the annual meeting of the Board for consideration.

On behalf of the Management committee, I want to express my thanks to all the volunteers and their supporting companies and agencies from the Canadian mining industry and government organizations across Canada. It is their contribution of time and expertise that is vital in maintaining the credibility of the MEND program.

I.J. Itzkovitch, Chairman
MEND Management Committee
April 18, 1996

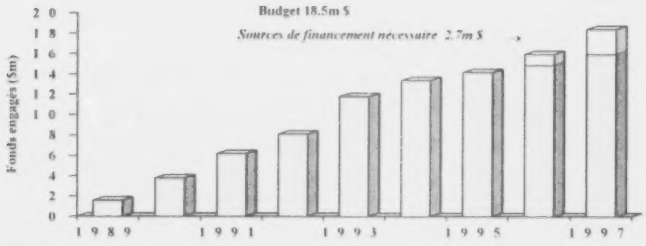
RÉSUMÉTECHNIQUE

Le programme NEDEM est arrivéau terme de sa septième année d'élaboration de technologies pour la prévention et le contrôl e du drainage acide provenant des déchets miniers et des ouvertures de mines. Au cours de l'année 1995, les comités du NEDEM ont poursuivis leurs tâches principales, soit la direction des activitésde recherche et le rapport convivial des résultats. NEDEM a contribué de façon appréciable à la réduction du fardeau financier de 3 à 5 milliards $ associée au drainage acide au Canada et s'est engagéà réaliser le programme convenu de travaux en respectant le budget et les délais approuvés par le Comité d'administration du NEDEM.

Pendant les dernières années du programme, NEDEM continuera d'insister sur la réalisation des projets approuvés et sur le transfert de la technologie en parrai nant plusieurs ateliers dans toutes les régions du Canada. Ces activitésdéboucheront sur la tenue de la 4eConférence internationale **sur le drainage rocheux acide,** à Vancouver, en 1997.

Tel qu'indiquédans la Figure 1, NEDEM est près d'atteindre son objectif et de respecter le plafond budgétaire de 18,5 millions $ approuvéen avril 1995.

Figure 1: Profil des dépenses du NEDEM en 1989-1997



En 1995, les **comités prévision et de surveillance** ont été réunis sous la coprésidence de MM. Bill Napier et Ed Kustan. Le **Comité de prévision** avait auparavant abandonné l'ambitieux programme de mise au point d'un modèle théorique de stériles au profit de l'approche empirique, c.-à-d., l'utilisation et l'analyse des données obtenues à partir de sites existants pour mettre au point des modèles simples de prévision de la production d'acide dans une halde de stériles. Grâce à cette approche, il a été possible d'élaborer des méthodes plus simples pour analyser les options de gestion des stériles produisant de l'acide aussi bien sur le site même que lorsqu'ils sont transportésà la mine. Des études réalisées à la mine Doyon ont permis de mettre en place une excellente base de données sur les stériles et ces données ont fait l'objet d'analyses exhaustives.

Une étude de terrain détaillée d'un autre type de stériles qui a débuté en 1995 sur un site de la mine Whistle, ainsi que des informations internationales, complétera les données compilées à la mine Doyon.

Le **Comité de prévision et de surveillance** a fait des progrès sur la documentation et l'amélioration des méthodes chimiques utilisées pour déterminer le potentiel et la vitesse de production d'acide des déchets miniers. De plus, ce comité participe avec le Comité de prévention et contrôle à un programme en vue d'évaluer la possibilité d'intervention technique dans le pergélisol afin de prévenir le drainage acide dans les régions septentrionales du Canada. À ce jour, les résultats démontrent que des données expérimentales sont nécessaire pour compléter l'information anecdotique.

Le projet final de surveillance, le manuel de surveillance, sera terminé en mai 1996 et présenté lors d'un atelier qui se tiendra à Saskatoon en juin.

En 1995, des progrès remarquables ont été réalisés et le programme de **prévention et de contrôle** a obtenu des résultats marquants. Trente projets ont été entrepris et 7 de ces derniers ont été complétés. La déposition subaquatique et les couvertures aqueuses continuent d'être les projets «vedettes» du NEDEM qui ne cessent de donner des résultats prometteurs. Les résultats ont conclus que:

- l'eau est l'élément-clé dans la prévention de la production d'acide - soit par la déposition subaquatique ou l'entreposage dans des fosses à ciel ouvert, en fournissant une barrière d'oxygène dans les «barrières sèches» et par les nappes phréatiques surélevées qui limitent l'apport d'oxygène; et

- les couvertures aqueuses sur les résidus et les stériles partiellement **oxydés** sont aussi intéressantes mais des mesures devront être prises, telles l'utilisation de couches superficielles de diffusion peu coûteuses et l'ajout de minéraux alcalins pour empêcher la contamination de la colonne d'eau jusqu'à l'établissement d'une surface de diffusion naturelle.

La technologie des couvertures aqueuses parrainée par NEDEM continue de faire l'objet de démonstrations sur le terrain. La fermeture de trois sites de résidus d'uranium à Elliot Lake est en cours, au moyen de couvertures aqueuses. Les projets du NEDEM ont été déterminants pour confirmer la technologie de fermeture. Pour remettre en état le parc à résidus de la mine Solbec Cupra, dans le sud-est du Québec, le propriétaire a utilisé les résultats des recherches du NEDEM et une comparaison économique pour prendre la décision d'inonder les résidus. La surveillance du site est présentement en cours. À l'ouverture de la mine de cuivre-zinc Louvicourt, dans le nord-ouest Québecois, on a procédé à la déposition subaquatique des résidus dans un lac artificiel et un programme de surveillance a été entrepris sur le site et en laboratoire. Le but de cette duplication est d'obtenir des outils économiques d'évaluation qui pourront être utilisés dans les mines futures pour les parcs à résidus par la méthode de déposition subaquatique. NEDEM continue de perfectionner les méthodes d'évaluation pour les couvertures aqueuses afin que les organismes de réglementation et les propriétaires puissent avoir confiance dans les résultats.

Des paramètres physiques et géochimiques font l'objet d'un examen en vue de l'élaboration de directives pour la conception de couvertures aqueuses peu profondes et pour la déposition subaquatique, un résultat important du programme

Les travaux relatifs aux couvertures organiques réductrices, aux couvertures multi-couches construites à partir de résidus et de résidus dépyritisés se poursuivent sur le terrain et en laboratoire. Ces trois technologies ont démontré des promesses sur des sites déterminés. Les travaux effectués sur les couvertures sèches de matériaux géologiques ainsi que sur les couvertures ne contenant pas de matériaux géologiques sont révisés par des pairs et les résultats seront présentés à l'occasion d'un atelier sur les couvertures sèches, à Sudbury, en avril 1996.

Le **Comité de traitement** a terminé les travaux portant sur les systèmes de traitement passifs en préparant un guide, sous forme de manuel, sur la possibilité d'appliquer des systèmes de traitement passifs au Canada. Les activités pour la durée du Programme NEDEM seront concentrées sur la stabilité et la déposition des boues traitées à la chaux. Les travaux réalisés en 1995 étaient axés sur la stabilité des boues.

Les activités liées au **transfert de la technologie** ont pris beaucoup d'envergure en 1994 et en 1995, ce qui se poursuivra jusqu'au terme du programme et possiblement au-delà. NEDEM a également accès à un site Internet (http://www.NRCan.gc.ca/mets/mend) qui permet d'obtenir en direct les rapports annuel et les résumés des documents NEDEM. Des ateliers NEDEM basés sur les résultats de projets NEDEM ont été présentés à quatre endroits au Canada et plusieurs autres ateliers seront organisés en 1996. Ces ateliers qui ont été présentés gratuitement ont été couronnés de succès et sont utilisés pour perfectionner les autres projets du NEDEM et pour préparer «des cours abrégés» aux fins de la conférence qui se tiendra en 1997.

Un «Manuel NEDEM» est en préparation. Ce manuel qui sera éventuellement publié en anglais et en français, comprendra des résumés de tous les travaux du NEDEM ainsi que des travaux associés sur le drainage acide des déchets miniers et des ouvertures de mines. Le manuel devrait être terminé en décembre 1998, soit un an après la fin du programme.

ORGANISATION DU NEDEM

En 1995, des dispositions ont été prises en vue de rationaliser les opérations des comités parce que la plupart des travaux prévus par deux des comités avaient été réalisés. Les comités prévision et surveillance ont tenu leur première réunion conjointe en juin, et le comité traitement a décidé de terminer leurs activités en juin 1997. Les relations internationales font maintenant partie de la fonction du transfert de la technologie.

À l'échelle internationale, l'intérêt manifesté envers les résultats du programme canadien NEDEM est toujours aussi vif et le réseau de contacts à l'étranger est en pleine expansion, en particulier en Amérique du Sud et en Extrême-Orient. Plusieurs sociétés et organismes se sont montrés intéressés à participer au NEDEM à titre de membres associés et ces relations s'amplifieront en 1996. Plusieurs

organismes étrangers envient le partenariat étroit entre les gouvernements et l'industrie tel que pratiqué par NEDEM.

Dans une période de restrictions budgétaires qui n'épargne ni les activités scientifiques ni les initiatives technologiques, certains partenaires précieux du NEDEM ont été sérieusement affectés. La décision prise, en 1995, de fermer le United States Bureau of Mines, a eu pour conséquence la perte de plusieurs membres actifs et reconnus dont la contribution a été grandement appréciée. Toutefois, au Canada, il est à remarquer que tous les membres du NEDEM, tant des gouvernements fédéral que provinciaux, en dépit des restrictions budgétaires, coupures de personnel et nouvelles priorités, continuent d'appuyer activement NEDEM. Ce soutien continu est reconnu et grandement apprécié.

CANMET, avec le soutien financier de l'Association minière du Canada, continuera de fournir les services du secrétariat requis à NEDEM, et ce, jusqu'en 1997.

Il est à remarquer que l'industrie continue d'appuyer fortement NEDEM. De nouveaux participants des comités du NEDEM ont démontré beaucoup d'enthousiasme et ont fréquemment renouvelé leur adhérence en 1995.

RAPPORT FINANCIER

L'engagement financier pris envers NEDEM par ses trois partenaires, soit l'industrie minière canadienne, le Gouvernement du Canada et les provinces se poursuit sans défaillance. Jusqu'en décembre 1995, 15,0 millions de dollars avaient été dépensés et engagés pour la réalisation de 160 projets de recherche terminés ou en cours que parraine NEDEM, tel qu'indiqué dans le Tableau 1.

Table 1 : Contributions au NEDEM, de 1988 à 1995 inclusivement (en milliers de dollars)

	Dépensées (%) Projets complétés	Dépensés et engagées (Projets en cours)	Total (%)
Industrie minière	5 531 (39.8)	359	5 890 (39.0)
Canada	4 936 (35.5)	646	5 582 (36.9)
Provinces	3 427 (24.7)	221	3 648 (24.1)
TOTAL	**13 894** (100.0)	**1 226**	**15 120** (100.0)

Du montant global de 15.0 millions de dollars dépensés ou engagés à ce jour, le Comité prévention et contrôl e a dépensé 9,2 millions de dollars, ce qui est comparable au budget total alloué au comité qui était de 10,5 millions de dollars.

En 1995, le Comité de gestion a demandé aux comités techniques d'accorder une priorité à tous les projets restants, d'examiner les priorités du comité et d'évaluer les montants nécessaires pour terminer le programme NEDEM. Les estimations sont indiquées dans le Tableau 2 ci-dessous.

Tableau 2: Établissement des priorités pour terminer le programme NEDEM : février 1996 (en milliers de dollars)

Comité technique	Approuvés, Besoin de financement	Priorité élevée	Priorité moyenne
Prévision/ surveillance	300	480	775
Prévention et contrôle	335	505	100
Traitement	60	150	
Transfert de la technologie	59	100	
TOTAL	754	**1 235**	875
(cumulatif)	(754)	**(1 989)**	(2 864)

Aux Tableaux 3 et 4 figurent les projets complétés ou en cours du NEDEM à la fin de l'année 1995. Au Tableau 5 figurent les projets qui sont soumis au Conseil d'administration pour approbation. Ces projets coûteront 1 390 000.00 $, pour lesquels un montant de 776 000.00 $ a été engagé par des partenaires de financement. Le budget du plan est de (18 468 000.00 $) et le total des fonds approvés (16 078 000.00 $) pour la réalisation des projets NEDEM font l'objet d'une comparaison par les comités techniques dans le Tableau 6. Au Tableau 6 est également présenté un résumé des budgets associés aux projets soumis pour approbation en 1996 (1 390 000.00 $). Le montant total des engagements pour la réalisation du programme est maintenant de 17 468 000.00 $.

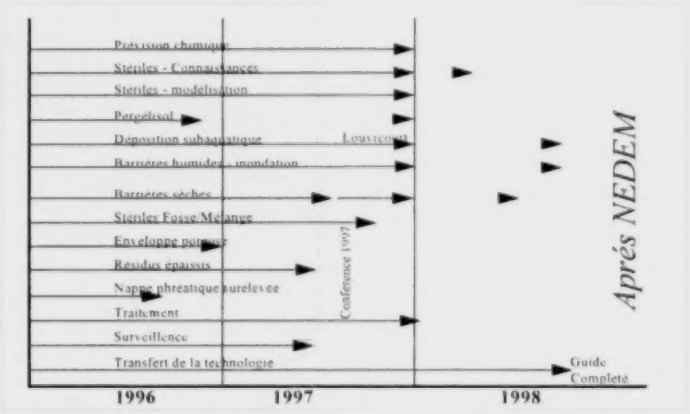
À ce jour, le financement est de 15 120 000.00 $ pour les projets approuvés plus 614 000.00 $ pour les projets proposés, ce qui fait un montant total de 15 734 000.00 $. **Pour terminer le programme NEDEM, un nouveau financement au montant de 2 734 000.00 $ sera requis et devra être trouvé.**

Les délais actuels prévus pour l'exécution des éléments clés sont indiqués à la figure 2. Étant donné la disponibilité des fonds dans les années antérieures, NEDEM devrait être en mesure de financer les projets à haute priorité et ceux qui ont été approuvés. Toutefois, en raison des coupures effectuées

dans tous les programmes gouvernementaux au pays, NEDEM pourrait recourir à un engagement encore plus important qu'à l'ordinaire de la part de l'industrie minière.

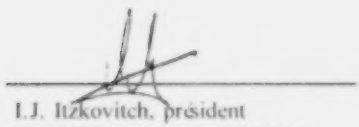
En 1998, un certain chevauchement sur le plan du transfert de la technologie et de la surveillance des résultats des couvertures aqueuses et sèches sera requis. Une autre raison pour laquelle le programme ne sera pas terminé dans les délais est le manque de fonds pour la réalisation de projets de type générique, comme par exemple, l'élaboration des lignes directrices.

Figure 2 : Date prévue pour mener à terme les projets des aires de recherche du NEDEM



Comme l'indique le Tableau 6, les comités techniques ont engagé une partie considérable de leurs budgets. Comme par les années passées, l'ensemble des engagements financiers envers le programme NEDEM demeurera une question sur laquelle le Comité d'administration devra se pencher. La réalité de la conjoncture économique qui prévaut actuellement au Canada doit être mise en rapport avec le besoin de réduire les obligations potentielles à long terme de l'industrie et des gouvernements sur le plan environnemental. Le Conseil d'administration souhaiterait peut-être également prendre en considération des options pour assurer le suivi du programme NEDEM ou la continuation de celles-ci. Plusieurs options méritant d'être considérées seront présentées à l'occasion de la réunion annuelle du Conseil d'administration.

Au nom du Comité de gestion, je tiens à remercier tous les bénévoles ainsi que les sociétés et organismes de l'industrie minière et des gouvernements du Canada et des provinces qui ont offert leur soutien. Leur contribution en temps et en compétences est primordiale pour le maintien de la crédibilité du programme NEDEM.



I.J. Itzkovitch, président
Comité de gestion du NEDEM
le 18 avril 1996

Table 3: Completed Projects

Project	Title	Budget ($000's)	Expenditures ($000's)	Variance ($000's)	Sponsors ($000's)
1.11.1	AMD from Waste Rock - Literature Review	50	50	0	Env. Can. (25), Teck (25)
1.12.1a	Compile AMD Prediction Data - Tailings & Waste Rock	45	44.6	0.4	B.C. (32.3), CANMET (12.3)
1.14.1	Field Evaluation Rock Hydrogeochemistry - Mine Doyon	362	362	0	Québec (94), Lac (134), Camb
1.14.2	Mine Doyon Phase II - Monitoring and Modelling	450	450	0	Cambior (75), CANMET (150
1.15.1	AMD from Open Pits - Equity Silver	55	53	2	B.C. (10), CANMET (10), Pla
1.15.2	AMD from Open Pits - Expansion and Verification of MINEWALL 2.0	88.0	86.1	1.9	Noranda (20.1), BHP Mineral B.C. (27.5)
1.16.1a	Evaluation of Prediction Techniques - Tailings & Waste Rock	70	63	7	CANMET (63)
1.16.1b	Manual of Chemical Evaluation Procedures	23	23	0	CANMET (23)
1.16.1c	Development of Static Evaluation Procedures	40	21	19	CANMET (21)
1.16.2a	Interlaboratory Program for Standard Material NBM-1	30	20	0	CANMET (10), Env. Can. (10
1.16.4	Evaluation of Static and Kinetic Prediction Test Data and Comparison with Field Monitoring Data for Selected Mines	27.2	21.2	6.0	Gilbralter Mines Ltd. (6.8), Pl Cominco (3.4), Teck (7.0)
1.17.1	Hydrogeochemical Investigation - Waste Amulet	235	285	(50)	CANMET (117), Noranda (16
1.19.1	Kinetic Tests for Cinola Gold Project	100	94.3	5.7	Env Can. (47), B.C. (25), City
1.19.2	Scaling Analysis of Acid Rock Drainage	21	15	6.0	Env. Can (15)
1.21.1a	Evaluate RATAP BMT Capabilities	80	80	0	CANMET (30)
1.21.1b	Workshop of Modelling Techniques - Tailings	70	73	(3)	CANMET (63), Falconbridge
1.21.1c	Prepare RATAP Users Manual	30	19	11	Env. Can. (19)
1.22.1	ANSTO Model at Heath Steele	145	145	0	CANMET (87.3), N.B. (22.7),
1.24.1	Development of Preliminary Modelling of Seepage Quality from Acid-generating Waste Rock Dumps	285	21	264	DIAND (21)
1.25.1	Development of a Soil Flux Model to Design Tailings Covers	49.5	55.8	(6.3)	CANMET (56)
1.26.1	Development of Modelling Methodology for Prediction of Seepage from Acid-generating Waste Rock	90	90	0	Env. Can. (30), B.C. (60)
1.31.1	Fundamental Reaction Kinetics - SIMS	95	98.6	(3.6)	Echo Bay (5), DIAND (18), O
1.32.1	Prediction and Prevention of ARD - A Geological & Mineralogical Approach	73	71.4	1.6	Env. Can. (52), Teck (3), HBM BHP (3), Placer Dome (3), Co
1.41.1	International Workshop on Waste Rock Modelling	10	7.8	2.2	CANMET (0.5), Noranda (0.8 Québec (0.8), B.C. (0.8), HBM Ontario (0.8), Teck (0.8)
1.41.2	ARD Waste Rock Monitoring Database	22	22	0	CANMET (22)
1.41.3a	Waste Rock Pile Monitoring Ontario - Phase I	60	21.74	8.26	CANMET (10.87), Ontario (1
1.42.1	Critical Review of Geochemical Modelling	60.0	64.0	(4.0)	CANMET (30.0), Ontario (30
1.51.1	Quantitative Analysis of Chemical and Biological Kinetics	12	11.8	0.2	Env. Can. (11.8)
1.51.2	Non-linear Modelling of Chemical Kinetics for AMD	30	34.6	(4.6)	Env. Can. (34.6)
2.11.1a	Evaluation of Existing Underwater Disposal Sites	210	220	(10)	B.C. (50), CANMET (70), HB
2.11.1b	Evaluation of Existing Underwater Disposal Sites	250	136	114	B.C. (5), CANMET (5), HBM Env. Can. (26), Placer Dome (

2.11.1c	Evaluation of Existing Underwater Disposal Sites	50	68	(18)	Placer Dome (68)
2.11.1d	Peer Review on the Subaqueous Disposal of Tailings	45	34	11	CANMET (32.4), Placer Dom

Table 3

Project	Title	Budget ($000's)	Expenditures ($000's)	Variance ($000's)	Sponsors ($000's)
2.11.2a	Literature Review - Metal Toxicology	16.3	16.3	0	Placer Dome (16)
2.11.3a,b,c	Evaluation of Underwater Disposal Site - Anderson Lake	400	410	(10)	HBM&S (214), CANMET (10
2.11.4a	Evaluation of Underwater Disposal Sites - Buttle Lake	250	250	0	CANMET (150), Placer Dome
2.13.1	Flooding of Exisiting Tailings Sites - Quirke Lake	835	835	0	Rio Algom (502), CANMET (
2.13.2a,b,c	Flooding of Exisiting Tailings Sites - Solbec Cupra	260	291	(31)	Cambior (100), CANMET (10
2.13.3	Flooding of Exisiting Tailings Sites - Falconbridge	170	170	0	Falconbridge (155), Ontario (1
2.14.1	Establish Vegetative Wetlands Over Tailings	100	30	70	Falconbridge (25), CANMET
2.17.1	Use of Elevated Water Table to Reduce and Control AMD	50	50	0	CANMET (25), Ontario (25)
2.20.1	Evaluation of Alternate Cover Materials	50	55	(5)	CANMET (25), Ontario (25),
2.21.1	Engineered Dry Covers for Tailings	230	216	14	Env. Can. (61), CANMET (35
2.21.2	Engineered Dry Covers for Tailings - Noranda	469	533	(64)	CANMET (161), Noranda (22
2.22.1	Assessment of Hardpan	150	100.5	49.5	Manitoba (101)
2.22.2a	Evaluation of Dry Covers Built from Mine Taillings	235	270	(35)	Québec (133), Inc (20), Lac (1
2.23.1	Documentation of Disposal Methods - Tailings & Waste Rock	75	75	0	B.C. (38), CANMET (37)
2.23.2a,b	Thickened Tailings Disposal (TTD) Method	148.7	155.7	(7)	Falconbridge (155.7)
2.23.2d	Geochemical Evaluation of TTD at Kidd Creek	250	260	(10)	Falconbridge (140), Ontario (6
2.23.3	Porous Envelope Disposal Method - Falconbridge	190	207	(17)	Falconbridge (116), Ontario (7
2.24.1	Vegetation Manual	35	33.5	1.5	CANMET (34)
2.25.1b	Reclamation of Sulphide Tailings Using Municipal Solid Waste Compost	130	86	44	Falconbridge (53.5), Ontario (
2.25.2	Design of an Organic Barrier Using Wood Waste - East Sullivan	431	210	221	Québec (210)
2.31.1a	Dry Covers on Waste Rock - Heath Steele	400	312	88	BM&S (172), New Brunswick
2.31.1b	Dry Covers on Waste Rock - Heath Steele	368	368	0	Noranda (121.3), N.B. (91.9),
2.32.1	Blending and Segregation of Waste Rock - Kutcho Creek	140	140	0	Somac (110), B.C. (15), CAN
2.32.3	Co-disposal of Tailings and Waste Rock - Mines Selbaie	96	96	0	Québec (76), CANMET (20)
2.32.2b	Injection of Mine Tailings into a Waste Rock Pile as a Method to Control AMD - Literature Review	10	10	0	Québec (10)
2.33.1	ARD Remediation Measures at Four Norwegian Mines	38.5	38.5	0	B.C. (19.3), Norway (19.3)
2.34.1	Cementitious Covers - Westmin	130	130	0	Westmin (100), CANMET (30
2.35.2	Lysimeter Covers for Waste Rock	275	275	0	Noranda (152), Québec (84), C
2.36.1	In-pit Disposal - Case Studies	50	50	0	Ontario (20), CANMET (20),
2.41.1a	Electrochemical Oxidation/Passivation of Sulphides	60	60	0	HBM&S (30), Lac (10), Norar
2.44.1	Microbial Plugging	100	100	0	CANMET (60), INCO (10), N
2.45.1a	Separation of Sulphides from Mill Tailings	75	65	10	Ontario (20), CANMET (20),
3.11.1a	Treatment of Acidic Seeps Using Wetland Ecology and Microbiology	230	281	(51)	INCO (166), CANMET (40), Env. Can. (50)
3.11.1b	Treatment of Acidic Seeps Using Wetland Ecology and Microbiology	250	273	(23)	INCO (83), CANMET (90), D Env. Can. (70)

3.11.1c	Treatment of Acidic Seeps Using Wetland Ecology and Microbiology	128	125	3	Env. Can. (27), CANMET (27 INCO (25), Denison (16)

Table 3: Completed Projects Continued...

Project	Title	Budget ($000's)	Expenditures ($000's)	Variance ($000's)	Sponsors ($000's)
3.11.1d	Treatment of Acidic Seeps Using Wetland Ecology and Microbiology	80	80	0	Env. Can. (20), CANMET (20
3.12.1	Assessment of Existing Natural Wetlands	40	40	0	Env. Can. (40)
3.12.2	Evaluation of Panel Wetlands	45	45	0	CANMET (22.5), Ontario (22
3.13.1a	Passive Treatment of Small Seeps*	(90)	(90)	0	(Noranda (60)), (CANMET (3
3.14.1	Review of Passive Treatment	60	60	10	CANMET (35), Ontario (25)
3.21.1a	Metals Recovery from Acid Mine Drainage	25	25	0	CANMET (10), Env. Can. (15
3.21.1b	Metals Recovery - IX	64	64	0	Teck (10), Falconbridge (4), O
3.21.2a	Removal of Metals - Chemical	100	90	10	Noranda (90)
3.22.1	Survey of Acid Mine Drainage Characteristics	15	15	0	Ontario (15)
3.31	Use of Lime Sludges for Capping*	(30)	(12)	(18)	Inco (6.7), CANMET (23.3)
3.32.1	Chemical Treatment - Review and Sludge Stabilization	60	60	0	Ontario (30), CANMET (30) Selbaie (10)
4.1.1	Field Methods Manual - Tailings	20	29	(9)	CANMET (29)
4.2.1	Decommissioning Criteria	15	15	0	Ontario (5), HBM&S (5), Hom
4.3.1	Standard Reference Materials - Tailings	50	50	0	CANMET (50)
4.3.2	Standard Material - Net Neutralization Potential	28	27.5	0.5	Env. Can. (25), CANMET (2.5
4.5.1	Field Methods Manual - Waste Rock	55	55	0	INCO (25), Homestake (10), E
4.5.2	Field Sampling QA/QC	9.5	9.5	0	Noranda (9.5)
4.5.3	ARD Technical Guide - Monitoring Section	53.7	53.7	0	CANMET (50), Env. Can. (3.7
4.6.1	Assessment of Geophysical Techniques	118	130.6	(12.6)	Ontario (38), CANMET (38),
4.6.2	Continuous Monitoring of AMD - Literature Review	50	50	0	Quebec (50)
4.6.3	Remote Monitoring Techniques - Review	60	60	0	Ontario (30), CANMET (30)
4.6.4	Piezocone Field Test	26.7	26.7	0	INCO (9), Ontario (17.7)
4.6.5a	Oxygen Consumption Measurements to Monitor Oxidation Rates in Tailings at the Copper Cliff Tailings Impoundment	11.0	9.8	1.2	INCO (11)
4.7.1	Optimum Sampling Frequency	27	27	0	B.C. (13.5), CANMET (13.5)
4.7.2	Biological Monitoring of Acid Mine Drainage	21	21	0	B.C. (10.5), CANMET (10.5)
4.7.3	Aquatic Invertebrate Monitoring	136	136	0	B.C. (75), CANMET (42), En
4.7.4	Acid Mine Drainage Sediment Monitoring	6.5	6.5	0	B.C. (4), CANMET (2.5)
4.7.5	Ion Speciation	35	35	0	B.C. (6), CANMET (6), Noran
4.7.6	Paleolimnology Techniques	16.5	16.5	0	Noranda (16.5)
4.8.1	Monitoring of the Flooded Solbec Pit	139	136.5	3.5	CANMET (30), Quebec (106.5
4.8.2	Sediment Sampling Probe - Field Application	51.1	51.1	0	CANMET (17), Falconbridge Ontario (17.04)
5.1.1a-c	Provincial Workshops	56	29.3	26.7	Ontario (9.3), Quebec (20)
5.2.1a-c	Communications Plan - CIMM Lectures, Brochures, TV Series	5	5	0	CANMET (5)

5.2.1d	Communications Plan - Video	150	127	23	Ontario (75), CANMET (75)
5.3.1	Laurentian Database	35	35	0	Ontario (35)

* Unsatisfactory completion - Removed from Program → Associate Status

Table 3

Project	Title	Budget ($000's)	Expenditures ($000's)	Variance ($000's)	Sponsors ($000's)
5.3.2	Expand Databases at Laurentian & UBC	40	12	28	Ontario (12)
5.4.1	ARD Technical Guide - version française	24	24	0	Québec (24)
5.5.1	Preliminary MEND Research Plan	25	25	0	CANMET (25)
5.6.1	Second International Conference on the Abatement of Acidic Drainage	137	137	0	CANMET (30), Teck (8), Env Rio Algom (4), Falconbridge (Noranda (20), Cambior (4), M B.C. (3), MAC (2), Québec (10
5.6.2	Third International Conference on the Abatement of Acidic Drainage	15	12	3	AMQ (4), Ontario (5), CANM
5.8.1	Economic Evaluation of MEND-Developed Technology	40	40	0	Ontario (40)
6.1	New Ideas - I	203	141	62	CANMET (44), DIAND (9.2) Noranda (10), HBMA's (15), O
6.2	New Ideas - II	95	95	0	CBCD (10), CANMET (30), Q (25)
	Totals	12,241.20	11,109.14	699.86	

Table 4: Active Projects

Project	Title	Approved Budget ($000's)	Expenditures ($000's)	Variance ($000's)	Sponsors ($000's)
1.12.1b	DBARD - Continuation	40	25	15	Env. Can. (20), CANMET (20
1.14.3	Mine Doyon Comprehensive Review	74.5	45.6	28.9	CANMET (37.5), Québec (37.
1.16.3	Critical Evaluation of Procedures to Determine the Potential of Mining Wastes to Produce Acid Rock Drainage	30	30	0	Env. Can. (20.0), HBMS (10.0
1.16.5	Identification of Variability in Static Prediction Test Protocols	50		50	
1.18.1a	Development of an Information System to Assist with the Interpretation of Static Acid-Base-Accounting Test Data	50		50	
1.21.2	Pyrrhotite Oxidation - Laboratory and Modelling Studies	110	60	50	CANMET (30), Ontario (30),
1.27.1a	Guide for Predicting Water Chemistry from Waste Rock Dumps - Phase I	35.0	15	20	CANMET (17.5), B.C. (17.5)
1.31.2	Residual Weathering Production Waste Rock Dumps	40	20	20	B.C. (20), Placer Dome (10)
1.32.2	Pyrite Oxidation - Lithological & Mineralogical Factors	40	19.1	20.9	B.C. (20), Homestake (5.3)
1.43.3b	Waste Rock Pile Monitoring Ontario - Laboratory and Field Measurements	290	209.1	80.9	CANMET (115.0), Ontario (1
1.43.4	Waste Rock Pile Monitoring - Low Acid Production	200	0	200	
1.44.1	Waste Rock Pile Disassembly - B.C.	30	35	(5.0)	Homestake (35)
1.61.1	Permafrost - Technical Review	32	32	0	DIAND (32)
1.61.2	Acid Rock Drainage Prevention and Control: Towards a Tailings & Waste Rock Strategy for Using Permafrost to Manage ARD	50	50	0	DIAND (50)
1.61.3	Permafrost - Cullaton Lake Data Analysis and Interpretation	10	25	(15.0)	Homestake (25)
2.11.1c	Peer Review of Subaqueous Disposal of Tailings - Phase II	30	40	(10)	CANMET (31), HBMS (9)
2.11.3d	Anderson Lake - 1995 Program	55	45	10	HBMS (30), Manitoba (12.5),
2.11.5a,b	Shallow Water Covers - Equity Silver (Physical)	80	74	6	Placer Dome (44), CANMET
2.11.5c	Shallow Water Covers - Equity Silver (Geochemical)	115	110	5	CANMET (121)
2.11.9	Underwater Disposal Sites - Design Guidelines	50	0	50	
2.12.1a,b	Man-made Lakes Disposal - Lowicourt	500	77	423	CANMET (342), Teck (35), A
2.13.2d	Monitoring of the Flooded Solbec Cupra Tailings Site	150	90	60	Cambior (27), Québec (92)
2.15.1a,b	Water Covers - Laboratory/ Field	487	383	104	Noranda (253), INCO (85), La
2.15.2	Metal Release after Flooding	200	0	200	
2.21.3a	Peer Review of Waite Amulet and Heath Steele Soil Covers	50	40	10	Cominco (47)
2.21.3b	Peer Review on Covers Made with Non - Traditional and Synthetic Materials	20	10	10	Manitoba (10), CANMET (10
2.21.4	Protocols for Engineered Dry Covers	30	0	30	
2.22.2b	Evaluation of Dry Covers Built from Mine Tailings - Field (Associate Status)	200 (412)	200 (412)	0 0	Québec (67), Inco (67), CANM Québec (133), Inco (133), CAN
2.23.2c	TTD - Tracer Study	78	70	8	Falconbridge (39), Ontario (29
2.23.3b	Design Parameters for Pervious Envelope and Porous Surround	25	0	25	
2.25.3	Assessment of Alternate Materials for Dry Covers (Associate Status)	280 (204)	280 (204)	0 0	Falconbridge (140), Ontario (7 Falconbridge (161), Ontario (2

2.31.1c	Additional Monitoring of Heath Steele Cover on Waste Rock	50	25	25	BM&S (25), CANMET (25)

Project	Title	Approved Budget ($000's)	Expenditures ($000's)	Variance ($000's)	Sponsors ($000's)
2.36.2	In-pit Disposal of Oxidized Waste Rock	166	125	41	Noranda (75), CANMET (50)
2.36.3	Review of Methods for Characterizing Waste Rock Before Disposing Under Water	30	0	30	
2.37.1	Layering of Waste Rock to Prevent ARD	50	0	50	CANMET (45)
2.37.2	Review of Methods to Prevent the Onset of ARD	50	5	45	CANMET (45)
2.37.3	Characterization of Test Materials from Samatosum Study	35	5	30	CANMET (22)
3.41.1a	On Site Treatment of AMD	41	41	0	MOEE (20), Falconbridge (21
3.41.2	Metal Sulphide Biomineralization	20	20	0	Env. Can. (20)
3.42.2	Lime Sludge Characterization & Stabilization	165	105	60	Brazil - CANMET Project (10
4.5.4	Environmental Handbook for Acid Mine Drainage Monitoring	65	10	55	CANMET (32.5), Ontario (32
4.6.5b	Laboratory Studies to Assess the Oxidation Potential of Waste Rock Representative of Pile Sized Material	15.0	16.9	(1.9)	INCO (15)
5.4.2a	AMD/ARD Handbook - Phase I	150	0	150	Ontario (75), CANMET (75)
5.6.3	Fourth International Conference on Acidic Drainage	80	10	70	CANMET (15), MAC (1), B.C
5.7.1	MEND Newsletter	20	3.5	16.5	CANMET (3.5)
5.9	Review of MEND	80	40	40	CANMET (40), Env. Can. (17 (5), Falconbridge (5), Teck (5) Dome (2)
	Totals	4,448.5	2,391.2	2,057.3	

Table 5: Projects Recommended for Board Approval

Project	Title	Proposed Budget ($000's)	Funds Required ($000's)	Commitments/Comments ($000's)
1.15.3*	Prediction of Water Quality in Partially Flooded Pits Containing Waste Rock	30	0	Cogema (30.0)
1.16.2b*	Additional Certified Reference Materials	150	150	
1.19.3*	Acid Rock Drainage Prediction Laboratory Project	54.7	0	Env. Canada (10.0), Cominco (44.7)
1.28.1a	Understanding Physical Mechanisms in AMD Waste Rock Piles - Phase I	45	5	Env. Canada (40.0)
1.28.1b	Understanding Physical Mechanisms in AMD Waste Rock Piles - Phase II	54	19	AECB (35.0)
1.41.5	Guidelines for Characterizing Waste Rock Piles	25	25	
1.62.1*	Freeze Control of Tailings - Site Characterization and Sampling	60	60	
1.62.2*	Freeze Control of Tailings - Low Temperature Acid Drainage Laboratory Testing	100	100	
2.15.3*	Laboratory Investigation on Oxidation from Resuspension in Water Covers	50	50	
2.18.1	Review and Documentation of Water Cover Applications	25	2	Ontario (15), Noranda (3.0), CANMET (
2.21.4*	Protocols for Engineering Soil Covers over Tailings and Waste Rock (increase in scope)	20	20	
2.22.3	Technical and Economic Feasibility of Using Desulphurized Tailings for Covers	150	0	Quebec (150)
2.22.4*	Composite Cover Using Tailings - Full Scale Site Monitoring		150	0CANMET (150)
2.25.3	Assessment of Alternate Materials for Dry Covers (increase in scope)	61	0	Falconbridge (61)
2.25.4*	Effectiveness of Paper Mill Sludges as Covers - Laboratory	50	50	
2.30.1*	Waste Rock Prevention and Control Guidelines	30	30	
3.42.3	Disposal of Lime Treatment Sludge	150	100	CANMET (50)
5.1.2	Workshops 1996	40	40	Various funders
5.4.2b*	AMD/ARD Handbook - Phase II	100	100	Quebec, MDA
5.7.2	CDROM Publication of MEND Reports	40	40	
5.8.1	Education Initiative	5	5	
	Totals	1,389.9	786.2	

* Require's Management Committee Review & Approval

Table 6: 1996 MEND Program and Budget ($000'S)

mmittee	Program Area	Approved Budget	Approved Projects	Proposed 1996	Remaining Balance
diction		3,844	3,503	519	(178)
nitoring		1,085	1,056		29
vention & ntrol	Underwater Disposal	2,098	1,974		124
	Wet Barrier	2,668	2,213	75	380
	Dry Barrier	2,485	2,160	431	(106)
	Waste Rock	2,110	1,809	30	271
	Disposal Technology	1,150	951		199
atment		1,644	1,384	150	110
hnology Transfer ew Ideas		1,384	1,028	185	171
tals		18,468	16,078	1,390	1,000

1.0 Introduction

The Prediction and Monitoring committees are now amalgamated to form a single entity program. One chairperson acts for the new combined committee where Monitoring is a sub-program of Prediction. The revised technical program for the Prediction committee is very ambitious for the remaining 2 years of MEND. To ensure focus in the remaining technical areas and to facilitate the delivery of technical objectives, the Prediction committee adopted a structure similar to that of the Prevention & Control committee. Five sub-program areas were identified as critical to the successful completion of the Prediction component of the new MEND program. Each of these areas is led by a "Champion", whose role is to ensure prompt delivery of a quality product. These five sub-programs are:

- Waste Rock Basic Knowledge
- Waste Rock Modelling
- Chemical Prediction
- Permafrost
- Monitoring

The remainder of the MEND program will be spent filling the knowledge gaps in these (five) major areas. A greater understanding of the fundamental characteristics of the components of acid drainage and in some cases predictive tools are the targeted result. With the exception of Monitoring, each of these areas and the associated projects are described below. Monitoring is described in Section 4.0.

1.1 Waste Rock Basic Knowledge

Accomplishments

A report containing a work plan to characterize the waste rock pile at Inco's Whistle Mine was completed. This report was used as a scope of work to request proposals to perform the field characterization of the waste rock pile. This work plan is also intended to be used as a template and to be transportable, with minor adjustments, to other waste rock piles that may be monitored in the future. Steps towards understanding the basic physical interactions in waste rock piles were taken in the form of two separate projects. The waste rock pile at the Eskay Creek site was disassembled during the summer of 1995. Qualitative information about the flow of water through the pile was obtained by applying diluted paint to the pile and following its path during dissection of the pile. (A final report is being prepared). A second project analysed the hydrogeological properties of waste rock piles based on a synthesis of data form four mine sites; Myra Fall, B.C., Island Copper, B.C., B.C. Elkview Mine, B.C., and Golden Sunlight Mine, Montana. Four hydrostratigraphic models were proposed to characterized waste rock piles; they differ depending upon material types and construction methods. A methodology is presented, based on kinematic wave theory, that relates the outflow hydrograph recorded in toe drains to large-scale parameters characterizing the hydraulic conductivity structure of the waste rock pile. The outflow in response to an infiltration event is treated as an integration of the outflows from different channel groups within the pile. Water transfer from the channels to the finer-grained matrix is taken account of in the analysis. Application to the Island Copper data set suggests that the approach holds promise as a means of characterizing large-scale flow processes in the waste rock pile.

Activities

The south dump at Mine Doyon afforded an excellent opportunity to study a waste rock dump in detail. Phase I (1.14.1) resulted in the instrumentation and detailed characterization of south waste rock dump, as well as long term prediction of acid generation potential using two independent methods. Phase II augmented the monitoring program initiated in Phase I. From the information collected, geochemical, physical and hydrologic simulation capabilities were developed. Important physical parameters such as climatic data, temperature profiles within the dump, total discharge of acid drainage from collecting ditches and chemical composition of the effluents were monitored on a regular basis. The Mine Doyon Peer Review is designed to examine all technical aspects of the project related to Mine Doyon and present specific recommendations for further research, monitoring or other work, in the context of current waste rock prediction capabilities. The project has thus far found that significant advances in the understanding of waste rock pile physical and chemistry were obtained from the Mine Doyon studies. The knowledge base of basic waste rock pile information is being augmented by a extensive monitoring program at a second waste rock pile.

Characterization of this waste rock pile at Inco's Whistle Mine has thus far yielded a comprehensive database of basic information after one year of monitoring. The information was obtained from five boreholes, four lysimeters built into the pile, seepage from the toe of the pile and results of various chemical and physical analysis.

A M.Sc. project at UBC (1.31.2) is attempting to develop the probable mechanisms that relate bulk mineralogy to the secondary products formed through the identification and characterization of weathering products retained in a waste rock pile from a dump-leach mine site. Estimation of the reactivity/stability of these secondary products under differing environmental conditions are also being made. The applicability of detailed lithological and mineralogical characterization to the prediction of acid rock drainage is being addressed through a Ph.D. program at UBC (1.32.1). The projects are slated for completion in the spring of 1996 and mid-1996, respectively.

Future Direction

A second waste rock pile for comprehensive monitoring is planned but a site has yet to be found. A waste rock pile that either has not begun to generate acidic drainage or generates low fluxes of acidic drainage is targeted. Basic information from this type of waste rock pile is essential to help reduce the incertainty of predicting the acid generation characteristics of waste rock piles whose net neutralizing potentials are not definitive.

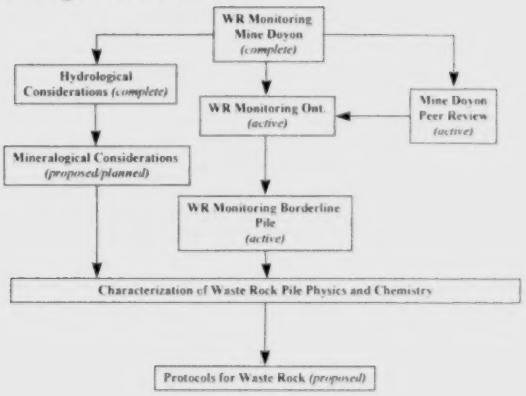
The projects related to this area are presented in a Table 7. The Waste Rock Basic Knowledge work plan is illustrated in Figure 3. Projects previously under the New Ideas area are also included in this table.

Table 7: Waste Rock Basic Knowledge

		Budget($)
Completed Projects		
1.31.1	Study of Weathering Employing SIMS	98.6k
1.32.1	Geological and Mineralogical Approach to ARD Prediction	71.4k
1.41.3a	Waste Rock Pile Monitoring Ontario - Phase I	21.74k
1.51.1	Quantitative Analysis of Chemical and Biological Kinetics	12k
1.51.2	Non-linear Modelling of Chemical Kinetics for AMD	34.6k
Active Projects		
1.31.2	Residual Weathering Products in Waste Rock Dumps	40k
1.32.2	Pyrite Oxidation - Lithological & Mineralogical Approach	40k
1.41.3b	Waste Rock Pile Monitoring Ontario - Phase II	290k
1.41.4*	Waste Rock Pile Monitoring - Low Acid Production (Borderline)	200k
1.44.1	Waste Rock Pile Disassembly - B.C.	35k
Recommended for 1996		
1.41.5	Guidelines for Characterisation of Waste Rock Piles	25k
Associate Project		
	Waste Rock Hydrogeology - B.C.	50k

* Approved project yet to be started

Figure 3: Waste Rock Basic Knowledge Work Plan


WR Monitoring Mine Doyon (complete)
Hydrological Considerations (complete)
WR Monitoring Ont. (active)
Mine Doyon Peer Review (active)
Mineralogical Considerations (proposed/planned)
WR Monitoring Borderline Pile (active)
Characterization of Waste Rock Pile Physics and Chemistry
Protocols for Waste Rock (proposed)

1.2 Predictive Modelling

Accomplishments

In 1990, a literature review on the physical and geochemical impacts of mines, a short term field investigation at Equity Silver, B.C., and the preliminary development of the program MINEWALL to simulate effluent quality from open pits were completed (1.15.1). The known limitations of the model code such as the arbitrary equations describing pit flooding and decreasing sulphide oxidation through time, and the inability to explicitly simulate effluent quality from underground mine walls were also addressed. Version 2.0 of the model was written as several individual, updatable modules and most of the programming effort to date has focussed on data entry. Field data was collected at the Island Copper and Bell Mine open pits in British Columbia. MINEWALL predictions were verified by mathematically comparing MINEWALL predictions against known outcomes using simplified data sets followed by complex data sets and finally by real data sets. The complexity of the MINEWALL II model has resulted in enormous amounts of computer code which cannot be handled by the current DOS-based programming language (Visual Basic). After consultation with the Prediction committee, the contractor simplified the computer code to retain user-friendliness without simulation of complex scenarios. The model was successfully applied to several mine sites.

A geochemical reviews project (1.42.1) was undertaken to identify the various geochemical processes occurring in waste rock piles at all stages of acid generation, and to list and thoroughly review existing geochemical models which are being used, or can be adapted, for predicting metal species and their concentrations in waste rock piles. The geochemical processes which most control ARD quality are precipitation and dissolution, chemical diffusion and surface reactions. Precipitation and dissolution control neutralization of acidic solutions and fixation of metals within solids. Chemical diffusion and surface reactions control the rates at which all precipitation and dissolution reactions occur. Quantitative reaction rates are required to accurately predict water quantity from waste rock piles. Reaction rate equations need to incorporate the important influence of rate-modifying mechanisms such as bacterial catalysis. Drying and wetting are the most important physical processes that affect water chemistry, by concentrating aqueous solutions to the point of precipitating solids and subsequently dissolving and removing these solids from solution contact. Field data required to describe geochemical processes in waste rock include temperature, oxygen availability and water infiltration rates. Thermodynamic and reaction rate data for important secondary minerals in ARD are insufficient. Existing geochemical models are divided into five classes: equilibrium thermodynamic models, mass transfer models, coupled mass transport-mass transfer models, supporting models, and empirical and engineering models. Each class of geochemical models can be viewed as addressing a different type of ARD prediction objective. A report is available and the results of the study were highlighted at a MEND workshop held in December 1995.

Activities

The feasibility of employing seepage data to estimate the future rates of metal release to the environment is currently being addressed. The 'empirical' modelling approach has seen success with limited waste rock seepage data and it is intended to verify and further refine this method. Alternative statistical-analytical methods to define trends in seepage data and imply mechanistic effects are also being addressed. Thus far, statistical correlation's between conductivity and constituents in mine seepages have been confirmed. Application of empirical approaches to seepage data is highly dependent on the size and quality of data in seepage databases.

Future Direction

Prediction of water quality in open pits has been successfully demonstrated. Expansion of the MINEWALL model to include flooded pits containing waste rock or tailings is planned. Accurate prediction of the water quality in these pits would provide operators with a tool to assess this waste management option. Previous projects have demonstrated that the chemistry and physics of waste rock piles are not chaotic and can thus be predicted through nonlinear techniques. A two-phased project to develop a coupled model to accurately predict acid generating

characteristics of waste rock piles is also planned (1.28.1a,b). The first phase will examine the mathematical techniques and determine the controlling factors that must be included in such a model. The second phase will be the preparation, validation and sensitivity analysis of the model. A user-friendly tool for determining the acid generating characteristics of waste rock piles under various close-out scenarios will result. A summary of Preditive modelling projects and the work plan for this area are shown in Table 8 and Figure 4 respectively.

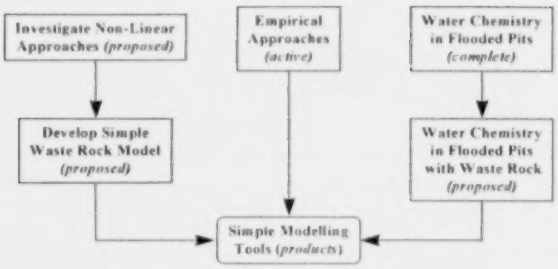
A study to quantify pyrrhotite oxidation in relation to relevant environmental conditions and to develop models to describe these reactions in tailings and waste rock has shown some interesting results (1.21.2). Results to date show that, unlike pyrrhotite dissolves in the absence of oxidants and that in solutions with pH values between 2 and 3, this oxidant-free dissolution occurs at rates similar to abiotic pyrite oxidation. Biological rates based on iron release is considered, however, biologic rates are relative to other oxidation reactions. Results suggest that the degree of oxidation of the sulphide sulphur in pyrrhotite depends on the oxidant present and the rate of reaction.

Table 8: Predictive Modelling

		Budget($)
Completed Projects		
1.21.1a	Evaluate RATAP BMT2 Capabilities	30k
1.21.1b	Workshop on Modelling Techniques	70k
1.21.1c	Prepare RATAP User's Manual	19k
1.24.1	Development of Preliminary Waste Rock Modelling	21k
1.25.1	Soil Atmosphere Flux Model to Design Tailings Covers	56k
1.26.1	Development of Modelling Methodology for Prediction of Seepage Quality from Acid-Generating Waste Rock	90k
1.14.2	Mine Doyon Phase II - Monitoring & Modelling	450k
1.15.2	AMD From Open Pits-Expansion/Verification of Model	86.1k
1.22.1	ANSTO Model at Heath Steele	145k
1.41.1	International Workshop on Waste Rock Modelling	8k
1.41.2	ARD Waste Rock Monitoring Database	22k
1.42.1	Critical Review of Geochemical Modelling	64k
Active Projects		
1.14.3	Mine Doyon - A Comprehensive Review	74.5k
1.21.2	Pyrrhotite Oxidation - Laboratory & Modelling Studies	110k
1.27.1	Guide for Predicting Water Chemistry from Waste Rock Dumps	35k
Recommended for 1996		
1.15.3*	Prediction of Water Quality in Partially Flooded Pits Containing Waste Rock	30k
1.28.1a	Understanding Physical Mechanisms in AMD Waste Rock Piles - Phase I	45k
1.28.1b	Understanding Physical Mechanisms in AMD Waste Rock Piles - Phase II	54.2k

* Requires Management committee approval

Figure 4: Predictive Modelling Work Plan


Investigate Non-Linear Approaches (proposed)
Empirical Approaches (active)
Water Chemistry in Flooded Pits (complete)
Develop Simple Waste Rock Model (proposed)
Water Chemistry in Flooded Pits with Waste Rock (proposed)
Simple Modelling Tools (products)

1.3 Chemical Prediction

Accomplishments

The current approach in setting up tests for evaluation of ARD material was assessed. An evaluation of the validity of current practices in scaling between bench, pilot and field scale for spatial, temporal, physical, chemical and biological processes involved in acid generation was successfully completed. The simple scaling laws which govern the geochemical and thermodynamic behaviour of pyritic rock piles are described by a single parameter, δ. This dimensionless scaling parameter combines information about pile porosity, pile size, effective reactive surface area, temperature dependence of the rate of pyrite oxidation, oxygen diffusion in the gas phase, heat of the pyrite oxidation reaction, thermal conductivity of waste rock, and ambient temperature. A sensitivity analysis provided information about the required accuracy of experimental tests and the relative importance of parameters governing different physical and geochemical processes responsible for ARD. These results offer the possibility of a cheap and fast preliminary assessment of the expected environmental impact as the model produces realistic results for acid generation rates. A M.Sc. project at UBC (1.16.4) studied the ability of chemical prediction data to indicate on-site water quality using a single mine site and the data from the DBARD database. All factors suggest that the extrapolation of laboratory data is more qualitative than quantitative.

Activities

Only minor changes to the data in the DBARD database are required for completion of this project. An investigation is being carried out to critically evaluate methods used to determine the neutralization potential of mining waste samples as part of prediction testing for acid rock drainage. The reporting of the results of neutralization potential (NP) determinations carried out by many laboratories do not include the exact conditions used, so that proper interpretation of data and the possible degree of overestimation, if it exists, cannot be assessed if variations in procedure are inadvertently or deliberately used by the laboratories. Back titration curves showed that an indication of the minerals contributing to the NP value obtained can be determined from the profile of the curve. Mineralogical characterization of a portion of the samples has yet to be completed.

Future Direction

The primary focus is the relationship between laboratory chemical predictive tests and data collection in the field. The effect of mineralogy is also being examined in the context of its effect on Acid-Base Accounting (ABA) results. It is appreciated that current static test methods are ambiguous and often rely on qualitative observations to yield

quantitative information which is routinely used in decision making processes related to mine waste management. In this regard, a project to determine the variability in static test protocols is under development. This will examine variability in terms of contribution to buffering from non-carbonate minerals and the effect of reaction rate to the static test results. Greater understanding of the significance of static test results and decreased variability in static test results will lead to the development of additional net neutralization potential (NNP) certified reference materials. The scaling analysis project (1.19.2) implied that a kinetic test protocol may be established that will yield substantially more information in short periods of time when compared to present kinetic, laboratory tests. This hypothesis will be tested in a project (1.19.3) aimed at examining the thermokinetics waste rock leaching at a laboratory scale.

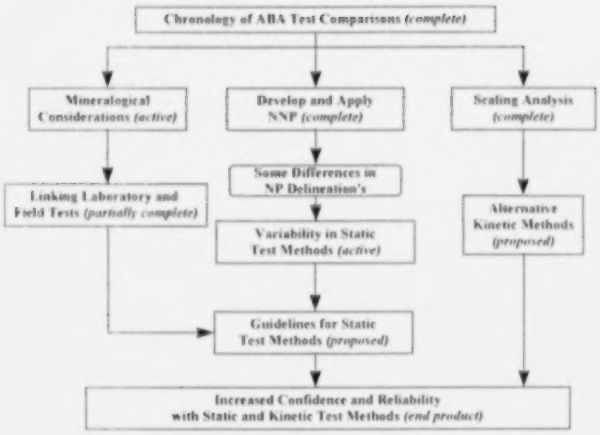
The activities in the project areas are summarized below and in a work plan shown in Figure 5.

Table 9: Chemical Prediction

		Budget($)
Complete Projects		
1.11.1	AMD from Waste Rock - Literature Review	50k
1.12.1a	Compile AMD Prediction Data (DBARD)	44.6k
1.14.1	Field Evaluation Rock Hydrochemistry - Mine Doyon	362k
1.15.1a	AMD from Open Pits - Equity Silver	53k
1.16.1a	Evaluation of Predictive Techniques	63k
1.16.1b	Manual of Chemical Evaluation Procedures	23k
1.16.1c	Development of Static Evaluation Procedures	21k
1.16.2	Interlaboratory Program for Standard Material NBM-1	20k
1.16.4	Evaluation of Static and Kinetic Prediction Test Data and Comparison with Field Monitoring Data for Selected Mine Sites	21.2k
1.17.1	Hydrogeochemical Investigations - Waite Amulet 1985/90	285k
1.19.1	Kinetic Tests for Cinola Gold	94.3k
1.19.2	Evaluation of Scaling - Bench, Pilot and Field Scale	15k
Active Projects		
1.12.1b	DBARD - Continuation	40k
1.13.1	Climatic Controls - Review	50k
1.16.3	Critical Evaluation of Procedures to Determine the Potential of Mining Wastes to Produce Acid Rock Drainage	30k
1.16.5	Identification of Qualitative Factors in Standard Static Prediction Test Protocols	50k
1.18.1a	Development of an Information System to Assist with the Interpretation of Static Acid-Base-Accounting Test Data	50k
Recommended for 1996*		
1.16.2b	Additional Certified Reference Materials	150k
1.19.3	Acid Rock Drainage Prediction Laboratory Project	54.7k

* Requires Management committee approval

Figure 5: Chemical Prediction Work Plan


Chronology of ABA Test Comparisons (complete)
Mineralogical Considerations (active)
Develop and Apply NNP (complete)
Scaling Analysis (complete)
Some Differences in NP Delineation's
Linking Laboratory and Field Tests (partially complete)
Variability in Static Test Methods (active)
Alternative Kinetic Methods (proposed)
Guidelines for Static Test Methods (proposed)
Increased Confidence and Reliability with Static and Kinetic Test Methods (end product)

1.4 Permafrost

Activities

Three projects are in the final stages of completion. A technical review is examining all literature relative to permafrost and will recommend options for future research. A second project is examining the physics and chemistry of tailings and waste rock management from a geothermal perspective. The objective is to define a strategy employing permafrost as a control of acidic drainage. The third project is analyzing the data from column leaching tests at low temperatures to determine the effect of temperature on acid generation rates and potential biological activity. Thus far it is apparent that further basic information is required to optimize the use of permafrost as a control for acidic drainage.

Future Direction

Two projects are recommended before the end of MEND to acquire basic information on tailings from a geothermal perspective. The first project would involve characterization of an active site in the continuous permafrost zone. Field data on various parameters would be established. Samples would also be collected for the subsequent laboratory studies. These studies would determine various parameters such as freezing point depression (add more). Together these projects would lead to a field test of an engineering design for freeze control of tailings in a continuous permafrost zone.

Permafrost projects in this area are summarized in Table 10 with a work plan shown in Figure 6.

Table 10: Permafrost

Active Projects

1.61.1	Permafrost Technical Review	32k
	Acid Rock Drainage (ARD) Prevention and Control: Towards a Tailings and Waste Rock Strategy for Using Permafrost to Manage ARD	50k

Review and I
of Kinetic Test
(a:

1.61.2		
1.61.3	Permafrost - Cullaton Lake Data Analysis and Interpretation	25k

Recommended for

1996*		
1.62.1	Freeze Control of Tailings - Site Characterization and Sampling	60k
1.62.2	Freeze Control of Tailings – Low Temperature Acid Drainage Laboratory Testing	100k

* Requires Management and Technical committee's approval

Figure 6: Permafrost Work Plan

2.0 Introduction

Seven **Prevention and Control** (P&C) projects were completed in 1995 and at year end about 21 projects were ongoing. To manage many activities more effectively, the P&C committee has sub-divided its research programs into five main areas: underwater disposal, wet barriers, dry barriers, waste rock and disposal technologies (formerly others). Prevention and Control is on track to deliver outputs listed in the 1992 Research Plan by the end of 1997 or early 1998.

2.1 Underwater Disposal

Early in the MEND program, consensus was developed that placing acid-generating materials underwater would prevent sulphide oxidation (underwater disposal is defined as the placement of **fresh, unoxidized tailings** underwater).

A work plan was developed in 1989, which consisted of evaluating four lakes where tailings were deposited. A preliminary evaluation and geochemical assessment on the interstitial water was completed (2.11.1 a,b and c) over two-year periods for each lake (Table 11). At the request of the MEND Board of Directors, a scientific and technical peer review (2.11.1d) of all work done was completed in 1992. This and presentations made to regulatory agencies provided feedback on the merits for using of subaqueous disposal to control reactive materials. Information deficiencies were also documented. A planning team of technical and scientific experts met in January 1993 and outlined a program which focused on field and analytical techniques to improve measurement of metal fluxes at the sediment/water interface and to clarify understanding of the reactivity of the substrate.

Three major field campaigns were conducted in 1993 - two on Anderson Lake and one on Buttle Lake. The basic elements of the original hypothesis have been successfully addressed, as the reactivity of the tailings studied in the 1993 programs has been demonstrated to be low. Companion studies included a literature review (2.11.2a), comparison of field techniques, and the establishment of quality assurance and quality control programs. In 1994, an assessment of mine-related inputs to Anderson Lake was carried out (2.11.3c) to determine, as much as possible, the extent of relationships between the various discharges and observed historical changes in lake chemistry. The most significant changes occurred immediately subsequent to tailings deposition.

Scientific and regulatory review and planning is a major part of the program, and is assisting in achieving a fair and objective study of the concept and methodology for subaqueous disposal of reactive tailings in lake. A second peer review of MEND studies conducted between 1993 and 1995 to assess the work in context with the original points of concern of the first peer review was started in 1995. The results of the second peer review were presented and discussed at the second technical overview meeting in Vancouver, June 1995.

Table 11: Underwater Disposal Projects

Completed Projects		Budget($)
2.11.1a	Evaluation of Existing Underwater Disposal Sites - 1988/89 Program	220.0k
2.11.1b	Evaluation of Existing Underwater Disposal Sites -	136.0k

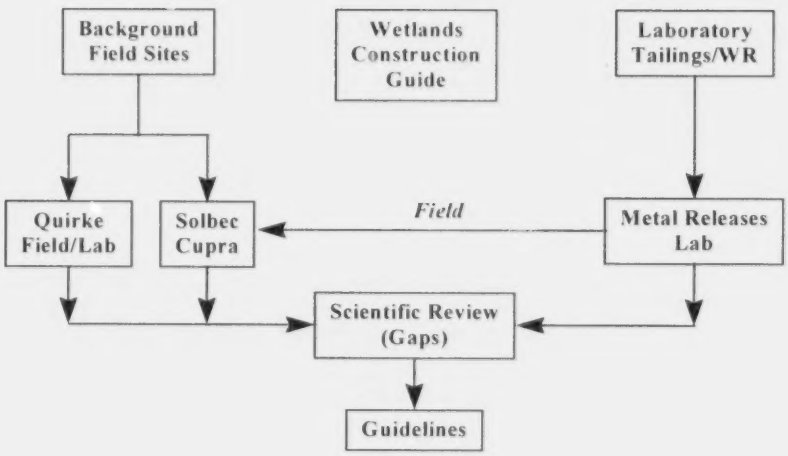
	1990 Program		
2.11.1c	Evaluation of Existing Underwater Disposal Sites - 1991/92 Program	67.6k	
2.11.1d	Peer Review on the Subaqueous Disposal of Tailings	34.4k	
2.11.2a	Literature Review Report: Metal Toxicology		16.3k
2.11.3abc	Evaluation of Underwater Disposal Site - Anderson Lake	410.0k	
2.11.4a	Evaluation of Underwater Disposal Site - Buttle Lake		250.0k
Active Projects			
2.11.1e	Peer Review on the Subaqueous Disposal of Tailings - Phase II	40.0k	
2.11.3d	Anderson Lake - 1995 Program	55.0k	
2.11.5ab	Shallow Water Covers - Equity Silver (Physical)	80.0k	
2.11.5c	Shallow Water Covers - Equity Silver (Geochemical)		115.0k
2.11.9	Underwater Disposal Sites - Design Guidelines	50.0k	
2.12.1ab	Man-Made Lakes Disposal Sites - Louvicourt Project	500.0k	
	Total	**1974.3k**	
Associate Projects			
	Study of Submarine (Ocean) Tailings Disposal		
	Subaqueous Disposal - Moose Lake ($320k)		

The main technical issues identified in the review was the extrapolation of estimates from a small area to the whole lake system. A secondary issue was the biological component which is considered site specific and for this reason it had decided that biological impacts would not be included in the MEND subaqueous studies. In general, the program was a significant step forward but some problems persist. The data supported the conclusion that very little recycling of metals occured from burried tailings. The question that remains on the release of metals is how little, since significant effects may occur with small releases.

At a Planning committee meeting in June, it was recommended that collection of additional water quality data prior to the commencement of tailings deposition (late 1995) and after removal of the mine rock road adjacent to the lake would further enhance confidence in several of the conclusions drawn from the Anderson Lake study. Tailings deposition ceased in 1994. And following start-up, an opportunity existed to assess the relative influence of all sources on lake water quality.

The data indicate improved water quality from August, 1993 to August, 1995 but show degradation immediately prior to the reintroduction of tailings into the lake. It is suspected that removal of the acid-generating material from adjacent areas may have exposed leachable material which is being flushed into the lake (2.11.3d). The overall Underwater Disposal program is shown schematically in Figure 7.

Figure 7: Underwater Disposal


Background Field Sites
Wetlands Construction Guide
Laboratory Tailings/WR
Quirke Field/Lab
Solbec Cupra
Field
Metal Releases Lab
Scientific Review (Gaps)
Guidelines

Several projects are currently underway at the Equity Silver tailings impoundment (2.11.5). This site is being used as a template to illustrate the dynamics of several key physical and chemical variables. The results from these studies are needed for the development of guidelines (2.11.9) for subaqueous disposal of tailings. The physical data collected in 1995 (2.11.5ab) will be used to evaluate the depth of water required in the cover to ensure that the bed will be physically stable enough to allow the geochemical gradients which inhibit acid generation to establish. Tailings reactivity (2.11.5c) is being addressesd using high-resolution observations (e.g. peepers) of trace metals and other sensitive indicators of chemical reactivity within the interstitial waters, and across the sediment-water interface.

A meeting of the Subaqueous Disposal Planning committee is planned for June 1996 to discuss the details of the guidelines document. This important meeting: will discuss the inclusion of biological factors and jurisdictional issues in the guidelines; review the status of the physical/chemical parameters projects at Equity; and attempt to identify who is in the best position to prepare such a document.

Underwater disposal of mine wastes in man-made lakes is presently an option favoured by the mining industry to prevent the formation of acidic drainage. Because of the potential controversy associated with using natural lakes for subaqueous disposal, there is considerable interest in evaluating whether artificial basins offer the similar advantages of natural lakes. The Louvicourt man-made lake tailings impoundment was chosen to help demonstrate the effectiveness of shallow water covers. The laboratory and field programs were initiated in 1995. Humidity cells, oxygen diffusion, sediment erosion, oxidation kinetics and the rate of residual and reaction product migration via surface and groundwater flow regimes and modelling downstream water quality and metal loadings are being investigated. The construction of the cells was delayed to 1996 due to other site activities. However, the field design manual and the instrumentation for the cells were purchased in 1995.

2.2 Wet Barriers

Comment: Figure 6 goes here

Distinct from underwater disposal, wet barriers refers to establishing a water cover on **oxidized** tailings. As with underwater disposal, continued oxidation is considered unlikely or is extremely low but the mobilization of the soluble salts becomes an important consideration.

results of the laboratory column leaching studies demonstrated that a shallow water cover, approximately 0.5m in depth, was very effective in reducing acid generation. In comparison to unsaturated coarse tailings, total productions of acidity, sulphate and iron were reduced by factors of approximately 300, 200 and 950 respectively when the tailings were flooded and maintained under a shallow water cover. The performance of the water cover is being evaluated by monitoring the flooded site for its hydrological parameters, surface and porewater chemistry, and sediment characteristics. These additional results will be made available to MEND by Rio Algom in the future.

Monitoring of the Solbec Cupra tailings site during flooding was continued in 1995 (2.13.2d). The monitoring program includes surface and ground water chemistry, hydrology, water balance (e.g. seepage, water depth), meteorological wave action (e.g. resuspension of particles), and the microbiological activity (Table 12).

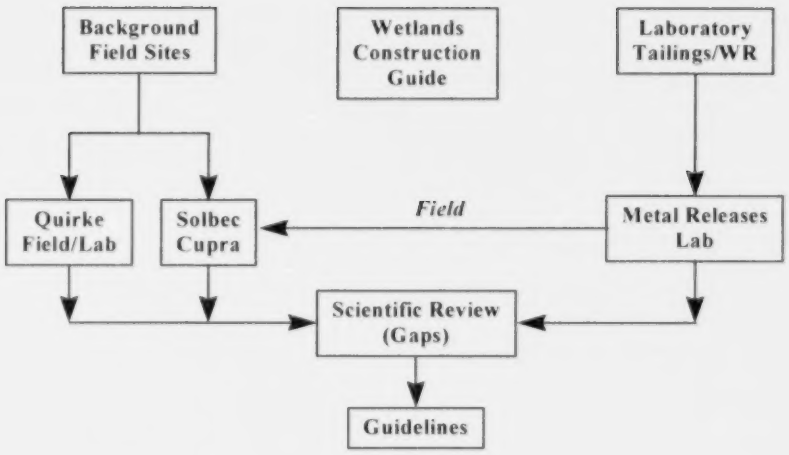
Work continued on the laboratory and field test program (2.15.1) to simulate the movement of total acidity and metal loadings from oxidation products under different flow regimes and to predict treatment requirements. Results from a column experiment where oxidized tailings are covered by 1m of water showed that transfer of zinc, sulphate, and iron from the tailings to the water column could occur, inducing reactions as pH decreased. These upward fluxes are influenced by hydrogeological conditions within the tailings and by the chemistry of iron minerals. The upward metal fluxes can last for long times, but decrease with time. Uncontrolled metal fluxes may signify the need to treat the water before releasing to the environment (2.15.1a). The upward fluxes can be limited with the addition of a layer of organic or inorganic material over the tailings. Results from the Mattabi tailings case study suggest that removal of zinc by treatment of surface and seepage water would be required for a long period after implementation of the water cover. The Mattabi test case was used to demonstrate the importance of early application of a water cover.

In report 2.15.1b, the most promising results to date were for columns containing an organic cover layer over the waste, where the organic matter not only consumed oxygen but produced ammonia alkalinity and reducing conditions within the waste material this prevented upward migration of contaminants from previously weathered and oxidized waste. The resulting alkalinity increased the pH to about 8 in the upper lying water column at the same time neutralizing the free acid as it migrated upwards from the oxidized waste below the organic cover.

In report 2.15.1a, it was recommended that work be carried out on the geochemical processes that influence metal releases in the short, medium and long term following flooding of a full scale site. Flooding at the Solbec Cupra site just reached (February 1996) the elevation where water is flowing over the control stucture. Monitoring of the site has began in a separate project (2.13.2d). Discussions are underway on the preparation of a scope of work which would include a detailed water balance for the site and long term hydrological and geochemical processes (2.15.2). Kinetic testing of various tailings materials to establish a geochemical comparison base for operators who are contemplating flooding for close-out was also recommended. The project will begin in the summer of 1996.

Many proposals for additional wet barriers research programs have been received and the committee recommended that prior to accepting the additional programs, a state-of-the-art literature review project should be completed. The objective is to collect, collate and interpret information on water cover design and implementation of research projects in Canada and elsewhere, to identify gaps in the application of water cover technology, and to make recommendations regarding the future direction of the Wet Barriers research area.

The Wet Barriers work plan is shown in Figure 8.


Background Field Sites
Wetlands Construction Guide
Laboratory Tailings/WR
Quirke Field/Lab
Solbec Cupra
Field
Metal Releases Lab
Scientific Review (Gaps)
Guidelines

The Wet Barriers work plan is shown in Figure 8.

Figure 8: Wet Barriers Flooding

Table 12: Wet Barriers Projects

		Budget($)
Completed Projects		
2.13.1	Flooding of Existing Tailings Sites - Quirke Lake	835k
2.13.2abc	Flooding of Existing Tailings Sites - Solbec Cupra	291k
2.13.3	Flooding of Existing Tailings Sites - Falconbridge	170k
2.14.1	Establish Vegetative Wetlands Over Tailings	30k
2.17.1	Use of Elevated Water Table as a Method to Reduce AMD	50k
Active Projects		
2.13.2d	Monitoring of the Flooded Solbec Cupra Tailings Site	150k
2.15.1ab	A Study on Water Covers for the Decommissioning of Mine Waste Disposal Sites	487k
2.15.2	Metal Releases after Flooding	200k
Recommended for 1996		
2.15.3*	Laboratory Investigation on Oxidation from Resuspension in Water Covers	50k
2.18.1	Review and Documentation of Water Cover Applications	25k
	Total	**2,288k**
Associate Project		
	Flooding of Existing Tailings Sites - Stekenjokk, Sweden	

* Requires Technical and Management committees approval

A study (2.17.1) evaluating the use of an elevated water table in sulphide-containing tailings to control and reduce acidic drainage was completed in 1995. The concept was studied at only a few tailings management areas, and was proposed for use at a few other sites. The report describes relevant theories, elevated water table concepts, and summarizes the limited empirical and scientific data currently available. The report concluded that the elevated water table concept has long term merits for the control of acidic drainage and a cost evaluation indicated significant potential benefits.

Comment: Figure 7 goes here

2.3 Dry Barriers

The use of soil covers appear to be an effective engineering solution in the management of acidic drainage particularly where a water cover cannot be maintained. In recent years, there has been more interest world towards developing a better understanding of the long term behaviour of soil covers as their performance appears to be encouraging. A contract to perform an independant review of both the Heath Steele (2.31.1) and Waite Amulet (2.21.2) projects was continued in 1995 (2.21.3a). The study also reviews important case studies from several regions of the world and recommendations are offered which warrant future research studies towards designing covers based on a rational approach.

The Heath Steele and Waite Amulet projects can be cited as two good soil cover examples. The design, selection of soil materials, construction, instrumentation, performance and economic evaluation that were carried out at the sites provided unique opportunities to observe the performance of the engineered soil covers in a Canadian climate. The extensive evaluation program at these sites brought into perpective several parameters concerning the design of soil covers.

Both covers were satisfactory and achieved their objective of minimizing the influx of water and providing and oxygen diffusion barrier to minimize the influx of oxygen using the capillary barrier concept.

The completed reviews were useful in providing some recommendations for possible future soil cover research. There is a need tor develope devices that can reliably predict suction measurements in the soil covers. More rigorous flow models based on rational approaches of taking into account several influences such as weathering are necessary for both the laboratory and field on a long term basis. Case histories on the performance of soil covers in various parts of the world would be helpful in understanding the mechanisms related to soil covers. Full scale models using varying degrees of conservativeness for various parameters comprise a useful to study to come up with economical designs for developing rational approaches for soil covers.

The objective of project 2.21.3a was to conduct a review of processes and methods for soil covers. While the tasks described in the work attempted to thoroughly encompass the dry cover area, this work did not attempt to address the many non-soil based covers gaining prominance (e.g. shotcrete, fly ash mixtures, cementitious materials, geosynthetics). A project was approved and started in 1995 (2.21.3b). This project is reviewing the properties of the various materials; will give a description of their application; and comment on their performance for potential use in acid mine drainage cover applications and requirements for future research.

The development of protocols follows the completion of the peer review (2.21.3a) and is expected to start in the summer of 1996. A dynamic type document to be distributed in loose leaf binder format for future updating is proposed. A catalogue of state-of-the-art practices which will help identify gaps and will open doors to new ideas for future research projects is suspected.

Cost-benefit analyses for some materials to be used for construction of dry covers make dry barriers appear uneconomical, but for many inactive tailings and waste rock sites, dry barriers may be the only option available other than perpetual treatment. The committee agrees that there is a need for the development of affordable dry barriers technology and future research should be directed on priority materials identified in the alternate cover materials project (2.20.1). The potential materials given a high priority include, among others, desulphurized tailings and paper mill sludges. The committee recommends for approval a project (2.22.3) to develop laboratory and computer methodologies of multi-layered covers constructed with desulphurized tailings (Table 13). A work plan to study paper mill sludges as cover materials is being prepared for technical and management committee approval.

Cover materials evaluated to date in laboratory and in companion field studies include composite clay/soil covers and plastic membranes (Waite Amulet). A laboratory project evaluated fine tailings as a lower cost alternative for the capillary material in layered cover systems when low permeability soils are not available at sites. The results confirm that sulphide-free fine tailings offer some promising characteristics as cover materials (2.22.2a). For example, if high saturation ($\geq 90\%$) can be maintained in the cover through capillary barrier effects, then a layer of fine material (i.e. tailings) sandwiched between two sand layers wouldl effectively reduce the oxygen flux to the reactive tailings material by a factor of about 1000 or more. A laboratory program (2.22.2b) to optimize the efficiency of cover designs and to further analyze the practical use of non-reactive tailings in layered cover systems started in 1995. This will result in a rational design process that could be used at different locations when only basic information (e.g. grain size, mineralogy) are known. A companion field program was also started. An analysis by the committee has shown that dry covers built from more than one layer of tailings deposited hydraulically has potential merit for saving costs. This field component used mechanical placement of the cover

materials thus increasing the cost associated with the placement and as a result the committee accepted the field portion ($412k of $600k) as an associate project.

Table 13: Dry Barriers Projects

Completed Projects		**Budget($)**
2.20.1	Evaluation of Alternate Dry Covers for the Prevention of Acid Mine Drainage from Tailings	55k
2.21.1	Engineering Dry Covers for Tailings - Laboratory	2k
2.21.2	Engineered Dry Covers for Tailings - Noranda	533k
2.22.1	Assessment of Hardpan	101k
2.22.2a	Evaluation of Dry Covers Built from Mine Tailings	270k
2.23.1	Documentation of Disposal Methods - Tailings and Waste Rock	75k
2.24.1	Vegetation Manual	34k
2.25.1	Reclamation of Sulphide Tailings Using Municipal Solid Waste Compost	8k
2.25.2	Design of an Organic Barrier Using Wood Waste - East Sullivan	210k
Active Projects		
2.21.3a	Peer Review of Waite Amulet and Heath Steele Soil Covers 50k	
2.21.3b	Peer Review on Covers made with Non-Traditional and Solid Waste Compost	2k
2.21.4**	Protocols for Engineered Dry Covers over Tailings and Waste Rock (increase in scope)	30k
2.22.2b	Evaluation of Dry Covers Built from Mine Tailings- Field	200k
2.25.3	Assessment of Alternate Materials for Dry Covers for Reducing AMD	280k
Recommended for 1996		
2.21.4*	Protocols for Engineered Dry Covers over Tailings and Waste Rock (increase in scope)	20k
2.22.3	Economic Evaluation on the Use of Tailings for Covers	150k
2.22.4*	Composite Cover Using Tailings - Full Scale Site Monitoring	150k
2.25.3	Assessment of Alternate Materials for Dry Covers for Reducing AMD (increase in scope)	61k
2.25.4*	Effectiveness of Paper Mill Sludges as Covers - Laboratory	5k
	Total	**2,591k**
Associate Projects		
	Engineered Dry Covers for Tailings - Curragh	
	Evaluation of Dry Covers Built with Mine Tailings - Field ($412k)	
	~~Assessment of Alternate Materials for Dry Covers for Reducing AMD ($204k)~~	

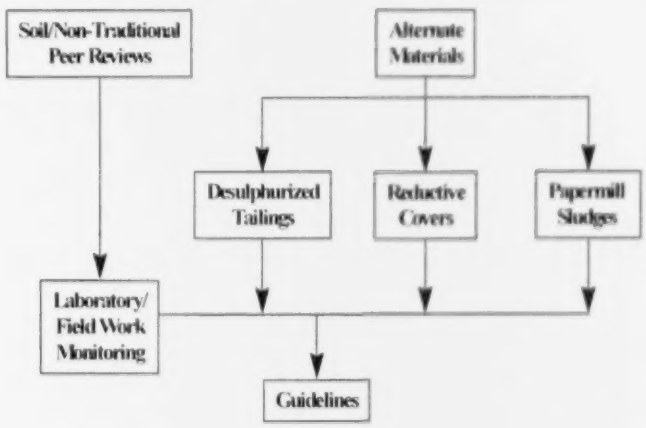
* Requires Technical and Management committees approval
** Approved project no yet started

Comprehensive, long term laboratory pilot scale work (2.25.3) to follow up on the potential benefits that were identified in previous studies (2.25.1 and 2.25.2) for organic type materials was continued in 1995. The pilot test program is comparatively evaluating the effectiveness of various organic cover materials (e.g. peat, municipal solid waste compost and lime-stabilized sewage sludge at limiting or reducing the impacts of acid generation on the environment from acid generating tailings. An inorganic cover material (desulphurized tailings) was also included in the study, both for comparative purposes and due to the economic availability of large volumes of this material at operating mining properties. The results to date from the pilot scale test cells show that, of all the materials tested, the lime stabilized sewage sludge performed best. It demonstrated high oxygen consumption ability, maintained a relatively constant moisture content throughout its depth, had a low surface evaporative flux, and maintained a relatively low rate of evaporative loss even under drought conditions. Underlying oxidized tailings pore waters have shown an increase in pH and a black band (i.e. metal sulphide precipitate) has formed at the tailings-cover interface since monitoring began. A detailed post-testing investigation on the large scale lysimeters. This project will yield better understanding of the relative effectiveness of the different measures in preventing and controlling sulphide oxidation controlled laboratory conditions is recommended for approval by the committee.

The Dry Barriers program is shown in Figure 9.

Figure 9: Dry Barriers

Comment: Figure 8 goes here



2.4 Waste Rock

Although some of the cover techniques available for tailings may be applicable to waste rock, the circumstances and methods of application are different. Waste rock piles have higher potential for developing induced air flows due to temperature gradients, porosity and differential settlement in the piles.

Monitoring of the Heath Steele composite clay/soil cover continued in 1995. The results clearly indicate reductions in the gaseous oxygen concentrations in the pile. Initial concentrations of 20%, prior to cover placement, were reduced to about 1%. Pile temperatures decreased following installation of the cover, but now appear to be controlled primarily by climatic conditions, rather than sulphide oxidation rates. Of critical importance for evaluating the effectiveness of the engineered soil cover, are results of the water chemistry from seepages emanating from the pile. The unique design of the cover allows a full water balance to be calculated, and this has shown an infiltration rate of about 2% of precipitation. However, the water quality of the effluent has not changed significantly. Some improvement in water quality and loadings were observed in 1995 (2.31.1c), with the exception of copper. Leachate quality remains above typical effluent discharge criteria. Monitoring of the pile will continue for another year (Table 14). The Heath Steele project was also the subject of the soil covers peer review (2.21.3a).

Laboratory evaluation of the relative effectiveness of various techniques for controlling acidic drainage in waste rock was completed in 1995 (2.35.2). The most effective method of controlling acid generation was water cover, followed by limestone, soil cover, phosphate and wood bark. The water covered waste began to release low concentrations of metals (zinc, iron and lead) after two and a half years of operation. The delay in metal release may be attributed to the presence of trace amounts of alkaline minerals which were probably depleted after two and a half years. The results indicate that, although a water cover may not completely prevent oxidation, it will reduce acid generation considerably. In fact, when considering both feasibility and efficiency, it is the most promising ARD technology known to the industry.

A case study review on the use of mined out pits as a repository for potentially acid generating materials was also completed in 1995. Good information has been obtained on: technical issues related to in-pit disposal; the diverse practices used and proposed; recently completed successful in-pit disposal programs; and issues/concerns associated with in-pit disposal of waste. The practice of in-pit disposal is more widespread than originally thought and it was found that detailed information on many of the identified sites does not exist. Twelve case studies were selected and are presented in detail in the report. A field program (at Owl Creek) was recommended but the committee decided that this would be too site specific, yielding few new insights. Thus no further work is planned in this area. A workshop to discuss in-pit disposal practices and possible future research areas was held in Sudbury in October, 1995.

Table 14: Waste Rock Projects

		Budget($)
Completed Projects		
2.31.1a	Dry Covers on Waste Rock - Heath Steele	312k
2.31.1b	Dry Covers on Waste Rock - Heath Steele	368k
2.32.1	Blending and Segregation of Waste Rock - Kutcho Creek	140k
2.32.2a	Co-disposal of Tailings and Waste Rock in Cells at Les Mines Selbaie	96k
2.32.3b	Injection of Mine Tailings into a Waste Rock Pile as a Method to Control AMD - Literature Review	10k
2.33.1	ARD Remediation Measures at Four Norwegian Mines	39k
2.34.1	Use of Cementitious Covers to Control Acid Generation at Westmin's HW Mine - Shotcrete Field Trial	120k
2.35.2	Lysimeter Evaluations of Cover Alternatives	279k
2.36.1	In-Pit Disposal - Case Studies	50k
Active Projects		
2.31.1c	Dry Covers on Waste Rock - Heath Steele	54k
2.36.2	Hydrogeochemistry of Oxydized Waste Rock and AMD Predictive Techniques	166k
2.36.3**	Review of Methods for Characterization of Waste Rock Prior to Underwater Disposal 30k	
2.37.1	Layering - Case Studies	50k
2.37.2	Methods for Delaying Onset of AMD - Case Studies	50k
2.37.3	Characterization of Test Materials from Samatosum Columns	35k
Recommended for 1996		
2.30.1*	Waste Rock Prevention and Control Guidelines	30k
	Total	**1,839k**
Associate Projects		
	Evaluation of the Effectiveness of Reclamation Measures at Mount Washington	
	Segregation of Waste Rock at the Samatosum Mine	

* Requires Technical and Management committees approval

** Approved project not yet to be started

The in-pit disposal project at Stratmat in New Brunswick originally consisted of both a field and laboratory component. The scope was reduced after approval was received to exclude significant field work. The new work plan concentrated more on the laboratory component including: investigating the immediate effects of dumping oxidized rock into fresh water; calculating the acidity inventory in the oxidized waste rock; evaluating the dissolution rates of different secondary minerals (i.e. oxidized products); assessing factors controlling the release of contaminants (e.g. solubility control, dissolution rate control, and diffusion rate control); and investigating the contaminant transport phenomenon by unsaturated flow within oxidized waste rock. MEND reviewed the revised scope and is in agreement that it remain a MEND project (2.36.2).

There is considerable uncertainty about the effect of secondary mineral solubility on water quality when oxidized waste rock is placed underwater. Discussions are underway on the development of a detailed work plan that would involve a literature review of prediction methods used to date and the development of a protocol for testing oxidized waste rock. The proposed protocol would then be tested in large scale pilot cells on several oxidized waste rock samples. The effectiveness of the recommended protocol would be evaluated and changes made, if necessary.

A case study review on the use of blending/layering as a close-out option for mines that contain both acid generating and non-acid generating waste rock was started in late December. The focus is to collect relevant information on practical field experience and to provide commentary on the implementation of this technique as a permanent prevention measures. The final report will be in sufficient detail to enable the reader to compare the cited case studies, their effectiveness and difficulties, practical problems and solutions to their own mining project.

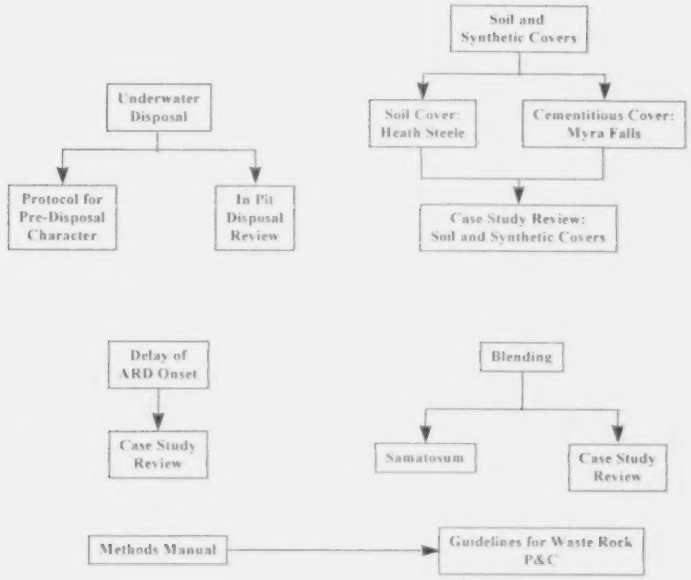
Methods for delaying the onset of acidic drainage and metal discharge may be appropriate when long term control measures are anticipated, but cannot be implemented immediately, for example, when relocation of the waste rock to a pit is planned after cessation of mining. A project to document the procedures and indicate the successes and failures on the use of temporary methods in a case study format has started and relevant information is being collected.

The combination of extensive field monitoring of the actual waste rock piles at Samatosum and the five years of column leachate monitoring provide a rare opportunity to compare laboratory simulations with the resulting performance of layering as a means of ARD prevention. Some proposed post-test analyses were recently started on column residues. ABA and post-metal contents will be determined and compared to pre-test results. Secondary minerals accumulation in the column waste rock will also be carried out. Based on the review of field-based and laboratory-based procedures and findings, recommendations will be made to improve the procedures and provide guidance to mines considering layering as a control technique for acidic drainage.

The work plan for Waste Rock is shown in Figure 10.

Figure 10: Waste Rock

Comment: Figure 9 goes here



2.5 Disposal Technologies

Originally this area was known as "Others" and included projects that would not logically fit into the other four areas. One such example is pre-treatment. This included chemical, or physical treatment that could prevent acid generation in either the short or long term. A project to synthesize a polymeric material with specific engineering characteristics was started several years ago (2.42.1). A number of approaches were attempting to synthesize various components of the required polymer; and most were not effective. Due to the death of the principal researcher the work was not completed. Two reports were prepared by graduate students but they did not achieve the objectives of the MEND study. It is therefore recommended that the project be removed from full MEND status (Table 15). No further work in pre-treatment is planned under this subcommittee and it was recommended during the priority setting excercise that the name be changed to "Disposal Technologies" to better reflect the efforts of the group. The Disposal Technologies work plan is shown in Figure 11. Another area being investigated is the effectiveness of new and existing disposal technologies for controlling acidic drainage.

The thickened tailings disposal (TTD) method is one of two disposal technologies being reviewed by MEND. The hydrological (2.23.2ab) study suggested that the

method was advantageous because of the low dissolved metal fluxes to the environment. In the geochemical study, completed in 1995 (2.23.2d), the hydrogeological flow system, the geochemical interactions and the influence of discharging tailings pore water on the quality of run off from the tailings during storm events were reviewed. The study revealed four distinct geochemical zones, with the bottom zone having high alkalinity and low dissolved metals, the zone above displaying high alkalinity with characteristics similar to original mill discharge water, a zone below surface layer where jarosite, a component of the Kidd tailings has affected the pore water. The surface layer exhibited limited oxidation to about 0.5m in depth. The hydraulic conductivity in the cone has been reported to be very low (10^{-8}m/s). Storm events studied at the site indicate that tailings pore water comprises between 0 and 23% of the total stream flow. The low effective specific yield of the thickened tailings causes a rapid water table rise during rainfall events. The greatest potential for discharge of significant solutes from pore water occurs while the water table is at or near surface. The geochemical - hydrogeological, and hydrological studies are confirming that the TTD method has benefits in terms of controlling acidic drainage.

The first set of results for the tracer study (2.23.2c) on the TTD system had higher than predicted velocities but subsequent sampling showed that the relative rates were actually slower and in the predicted range. In early 1995, the tracers were not detected because of dilution. Core sampling, in addition to regular monitoring, was completed in September 1995. The chemical tracer potassium iodide was detected in the core samples using lower detection limits during the analyses. Kidd Creek is proposing additional core samples (9 in total) at strategic locations between the three test sites in 1996. The results will be used to calibrate models on the performance of the TTD method with respect to seepage and contaminant transport.

Table 15: Disposal Technologies

Completed Projects		**Budget($)**
2.23.2ab	Hydrogeological and Geochemical Analysis of TTD System at Kidd Creek 156k	
2.23.2d	Geochemical Evaluation of the TTD System at Kidd Creek	250k
2.23.3	Porous Envelope Surround Disposal Method - Falconbridge 207k	
2.41.1a	Electrochemical Oxidation/Passivation of Sulphides - Small Scale Scoping Studies	60k
2.42.1	Development of Synthetic Polymers - Laurentian University *(45k)	
2.44.1	Microbial Plugging of Mine Tailings to Reduce the Production of AMD 100k	
2.45.1a	Separation of Sulphides from Mill Tailings - Phase I	75k

Active Projects

2.23.2c	A Tracer Study of Fluid and Contaminant Movement in the Upper Surface of the TTD System at Kidd Creek	78k
2.23.3b**	Design Parameters - Pervious Envelope and Porous Surround Methods	25k
	Total	**916k**

Associate Project

Separation of Sulphides - Field ($110k)

* Removed from full MEND Status

** Approved project not yet started

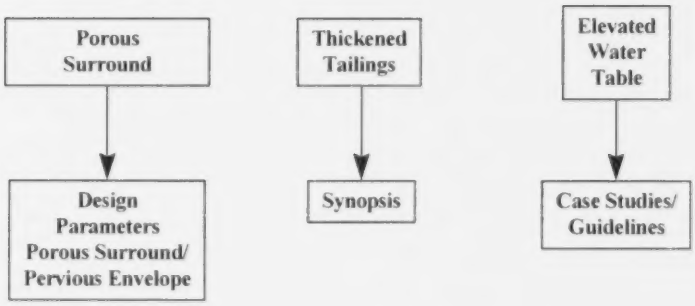
The second disposal technology evaluated was the porous surround/pervious envelope concepts. These are based on the fact that ground water flow into low permeable tailings masses can be minimized if high permeable soils are placed adjacent to and surrounding the tailings. If the permeability contrast between the natural soil and tailings are sufficient, ground water penetration into the tailings mass will be eliminated or reduced to acceptable levels. Leaching of the tailings is then theoretically reduced to acceptable levels, creating a permanent, cost effective, maintenance free tailings abandonment strategy

Conditions for porous envelope contraintment may be occuring at the Fault Lake site. Sulphide oxidation was detected tailings site, but geochemical processes have been attenuating acidity and metals in the tailings mass. Mineralogical analysis and acid-base accounting indicate that the carbonate mineral reserves are available for short term neutralization of acid and silicate minerals are plentiful for longer term buffering. High oxidation rates have been observed since deposition was discontinued in 1978, yet little impact was observed in the groundwater due to the porous envelope effect. Attenuation of the sulphide oxidation products is achieved primarily through the neutralization potential (NP) of the tailings, with the porous envelope effect acting in areas of depleted NP and where preferential flow was measured.

A project to evaluate the design parameters and basic principles needed to obtain a pervious envelope/porous surround effect was approved in 1995 (2.23.3b). Since then the MEND Secretariat has learned that a document reviewing the pervious envelope concept is in preparation by a Saskatchewan uranium producer as part of their Environmental Impact Statement. As a result, it is suggested that the project be delayed until proper review of the document is completed by the Prevention and Control committee. Although conceived for use as a disposal method for uranium mill tailings, the concept is, however, considered to have potential applications for other wastes.

Figure 11: Dispo-al Technologies

Comment: Figure 10 goes here


Porous Surround
Design Parameters Porous Surround/ Pervious Envelope
Thickened Tailings
Synopsis
Elevated Water Table
Case Studies/ Guidelines

3.0 Introduction

The **Treatment committee** met once in 1996, at Sydney, Nova Scotia, following a successful workshop on the prevention and treatment of acid mine drainage control in the coal and metal mining industries.

Program projects are listed in Table 16 and the balance of the program is shown in Figure 12

3.1 Passive Treatment Methods

The Treatment committee concluded that the use of passive systems to treat acidic seepage is technically feasible but the performance, cost and the applicability of these systems remained uncertain. Several process-limiting factors, such as temperature, flow rates, and rates of addition of bacteria nutrients, had been identified. In order to summarize the results, the committee decided in 1994 to conduct a summary review of passive treatment systems for the Canadian environment. The contractor's report was received in draft in March 1995 and it was decided that additional emerging technical information from international projects would be added to complete the work. This phase II report is due in April 1996, and will form a major part of the MEND Manual chapter on passive treatment. A short course will be given at the 1997 conference.

In general, it is concluded that passive systems have limited application to base metal acidic drainage in Canada. The principle reasons are:

- slow rates of reaction at cold temperatures;
- substrate fouling by elevated levels of aluminum and iron, and;
- rapid spring run-off at most mine sites.

However, passive systems have potential at remote sites that treat incidental seeps from waste rock piles or small flows of mine waters.

A small project on the use of organic-rich pervious reactor walls continued and the results indicated that the method has practical promise for treating contaminated groundwater plumes originating from tailings.

3.2 Metals Removal From AMD

Three projects were conducted on the removal of metals from acidic drainage before lime neutralization. Bench-scale tests on selective precipitation and ion exchange were completed in late 1993 and late 1994 respectively. Reports on both options

were published in 1995. Based on the recommendations in the laboratory-scale studies, neither ion exchange nor the selective precipitation technique will be tested on a pilot scale. The budget allotment was switched to sludge and treatment products stabilization.

3.3 Lime Treatment and Sludge Stabilization

Following the completed project on the review of lime treatment technology and production of a manual on lime treatment, the major emphasis for the balance of the MEND Treatment program will include the determination of methods to stabilize and disposel of lime treatment products.

The report on lime treatment recommended that investigations were needed on the stabilization of lime treatment sludges. This recommendation was reinforced by industrial and government participants at the 3 chemical treatment workshops across Canada. There was also the recommendation that several industrial uses of lime treatment sludges be investigated.

In 1995, a project was started to evaluate chemically and physically lime treatment sludges from several active treatment plants across Canada. Ten sites were visited and samples collected for laboratory investigations.

3.4 Committee Mandate and Operation

Although only one major project area remained at the end of 1995, that of lime sludge stabilization and disposal, the committee decided to remain active until at least June 1997.

Table 16: Treatment

Completed Projects		**Spent($)**
3.11.1a-d	Treatment of Acidic Seeps Employing Wetland Ecology and Microbiology - 1988-93	759k
3.12.1a	Assessment of Existing Natural Wetlands Affected by Low pH, Metal Contaminated Seepages - 1990	40k
3.12.2	Evaluation of Wetlands at the Panel Dam "A" Site	45k
3.13.1a	Treatment of Small Seeps	*(90k)
3.14.1	Review of Passive Systems for Treatment of AMD	60k
3.21.1a	Metals Recovery from Acid Mine Drainage	25k
3.21.1b	Metals Removal from Acid Mine Drainage - Ion Exchange	64k
3.21.2a	Metals Removal from Acid Mine Drainage - Chemical	90k
3.22.1	Survey of Acid Mine Drainage Characteristics	15k
3.31	Lime Sludges for Capping	*(12k)
3.32.1	Lime Treatment - Review and Sludge Stabilization	60k

Active Projects		**Budget ($)**
3.41.2	Biological Fixation of Sulphides	20k
3.41.1a	In Situ Treatment of AMD	41k
3.42.2	Lime Sludge Stabilization	165k

Recommended for 1996

3.42.3	Lime Sludge Disposal	150k
	Total	**1,534k**

Associate Projects

Field Evaluation of Acid Mine Water Treatment Using Constructed Wetlands at the Halifax Airport
Constructed Wetland at Noranda Bell Mine
Treatment of Acidic Seepage Using Chinese Alders
Use of Fluidized Bed Combustion Ash to Treat AMD (Nova Scotia)
Use of Lime Sludge to Cap Waste Rock (New Brunswick)
* Treatment of Small Seeps
* Use of Lime Sludges for Capping

* Removed from full MEND Status - Associate project

Figure 12: Treatment 1995-1997

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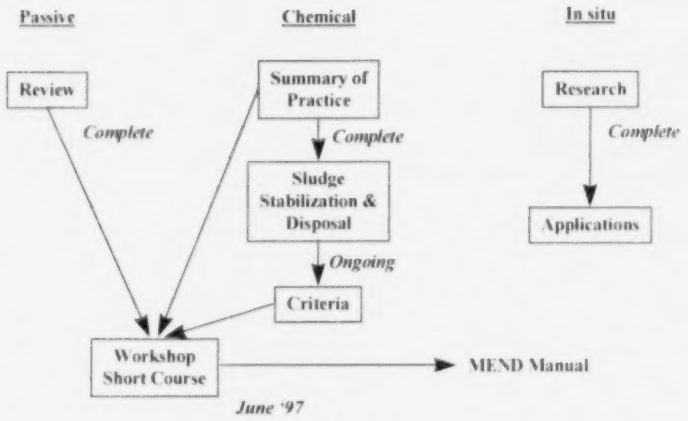


4.0 Introduction

The Monitoring committee was amalgamated with the Prediction committee in 1995 where Monitoring is now a sub-program of Prediction. A project recently completed (4.6.5a) demonstrated a new, facile method for measuring the oxidation potential of tailings. Application of the techniques to waste rock is nearing completion (4.6.5b).

A third project slated for completion in 1996 is the preparation at a manual on monitoring acidic drainage. This represents the culmination of Monitoring activities under MEND. The project entails the preparation of a manual to be used by industry and government agencies to achieve consistency in implementing monitoring programs, developing comparative databases, and to assist in the use of appropriate scientific techniques for monitoring. The Monitoring projects are presented in Table 17.

The overall direction, both past and present, of the Monitoring committee is presented in Figure 13. All projects are inter-related and ultimately tie into the Monitoring Manual.

Figure 13: Monitoring Program

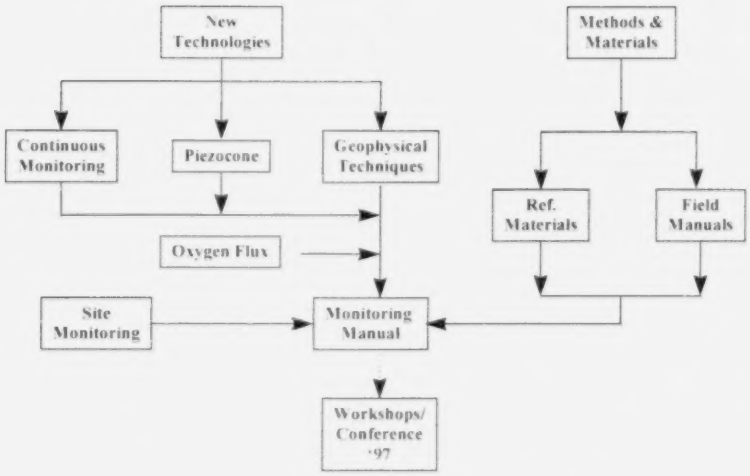


Table 17: Monitoring

		Budget($)
Completed Projects		
4.1.1	Field Methods Manual - Tailings	29k
4.2.1	Decommissioning Criteria	15k
4.3.1	Standard Reference Materials - Tailings	50k
4.3.2	Standard Material - Net Neutralization Potential	28k
4.5.1	Field Methods Manual - Waste Rock	80k
4.5.2	Field Sampling QA/QC	10k
4.5.3	ARD Technical Guide Revision - Monitoring Section	54k
4.6.1	Assessment of Geophysical Monitoring Methods	118k
4.6.2	Continuous Monitoring of AMD - Literature Review	50k
4.6.3	Remote Monitoring Techniques - Review	60k
4.6.4	Piezocone Field Test	27k
4.7.1	Optimum Sampling Frequency	27k
4.7.2	Biological Monitoring of AMD	21k
4.7.3	Aquatic Invertebrate Monitoring	136k
4.7.4	AMD Sediment Monitoring	7k
4.7.5	Ion Speciation	35k
4.7.6	Paleolimnology Techniques	17k
4.8.1	Monitoring of the Flooded Solbec Pit	139k
4.8.2	Sediment Sampling Probe - Field Application	51k
Active Projects		
4.5.4	Environmental Monitoring Handbook for Acid Mine Drainage	80k
4.6.5a	Demonstration of a Field Method to Determine the Oxygen Flux Across the Surface of Tailings	11k
4.6.5b	Demonstration of a Field Method to Determine the Oxygen Uptake of Waste Rock	15k
Withdrawn Project		
4.6.1b	Geophysical Monitoring: Further Application & Development	(100k)
Associate Project		
	Remote Sensing to Monitor Uranium Tailings Sites - AECB	(88k)
	Totall	1,060k

5.0 Introduction

With MEND winding down, **Technology Transfer** is becoming an increasingly important activity for the MEND program and will continue to be post-MEND. During 1995, the committee held 4 teleconferences and continued to broaden its activities in order to transfer technology to the users. The full program is listed in Table 18 and the components remaining to complete are shown in Figure 14.

5.1 Workshops/Conferences

Workshops were presented in Sydney on Acid Mine Drainage Control in the Coal and Metal Mining Industries, in Sudbury on In-Pit Disposal Practices and Lime Treatment and in Montréal on Chemical/Mathematical Prediction of Acid Mine Drainage. Once again these workshops were very successful and served as an effective vehicle for technology transfer. To date over 400 participants have attended the MEND workshops. Six additional workshops are planned for 1996 on various topics including: dry covers, monitoring and prediction. Workshops will continue to be delivered up to 1997 when short courses are planned at the Fourth Conference on the Abatement of Acid Rock Drainage.

This conference is planned for May 31 to June 6, 1997 in Vancouver, British Columbia. The theme of this conference will be "**Application of Technology**" with technical sessions addressing basic research, case studies, control, monitoring and financial assurance. Short courses will be offered prior to the conference on several acidic drainage related topics. Post-conference technical tours and a trade show round out the conference program.

Twelve MEND projects/papers were presented at the "Sudbury '95" conference in May, 1995. Ontario (MEND Ontario) and Québec (Comité consultatif sur le drainage minier acide du Québec) are planning workshops in 1996.

5.2 Communications/Publications

In addition to the publication of MEND reports, the MEND Newsletter is distributed to over 650 individuals and organizations to keep them informed of the recent results of MEND projects. One issue of the Newsletter was published in 1995, the publication will continue in the remaining two years of the program on a more frequent basis.

Four communication vehicles had been identified in 1993 to inform key audiences about the issue of acidic drainage and the new affordable technologies being developed to solve the problem. The vehicles were the CIMM Distinguished

Lectures Series, a print brochure to convey basic information about AMD and MEND, a series of television programs on the mining industry, and a video on AMD and MEND.

Mr. Louis Sirois was nominated as CIMM distinguished lecturer. Mr. Sirois made six presentions to local CIMM branches, all of which very well received.

Considerable effort was expended by many volunteers and the MEND Secretariat in providing material and editing of a video on MEND and acidic drainage. A 20-minute version for "technical" audiences has been produced along with a 12-minute version for the general public. Both versions, which are available in both English and French, were distributed in May 1995. The technical version will soon be available in both Portuguese and Spanish.

MEND has assumed the responsibility for report distribution from CANMET. This direction will provide more information as to where and to whom MEND reports are being distributed and which areas of technology development are of most interest. All MEND reports will soon be available in electronic format.

On October 1, 1995, MEND officially launched its home page and is now accessible via the Internet (http://www.NRCan.gc.ca/mets/mend). The home page includes the executive summaries of many MEND reports, the annual report, information on the 4th ICARD, the MEND organizational structure and links to other related Web sites. To date there have been over 1100 visitors to the MEND home page.

Work has commenced on the production of a "MEND Manual" that will be available at the end of the program. The Manual will summarize the results of MEND and will include the results of important technology developed outside of MEND. The report will contain general chapters on acidic drainage and the MEND program as well as detailed summaries with respect to various technological areas. This manual will be prepared in 2 phases, with Phase I ending in March 1997, and Phase II ending in June 1998. Phase II will include all of the results of the program and will be in English and French.

5.3 Databases

In 1995, the Technology Transfer committee again reviewed the functioning and usefulness of the Laurentian University Database. The over 10,000 abstracted references on abandoned mines, acid mine drainage and land reclamation are being reviewed for relevance to the MEND program. The database will be partitioned into abandoned mines and acidic drainage records. A link to the Laurentain Library (for access to the database) has been added to the MEND home page. The committee recommended limiting furthur effort applied in managing the database.

Two databases have been developed at the University of British Columbia through the Prediction committee. They focus specifically on the prediction of acidic drainage and on data management. The DBARD (Database for Acid Rock Drainage) project (1.12.1ab) will continue adding information until 1996, while the Waste Rock Dump Monitoring Database project (1.41.2) was completed in March 1994.

5.4 Intellectual Property

An Intellectual Property issue for MEND in 1995 dealt with access to MEND reports via the home page. There was some concern as to the possibility that the reports could be taken and altered. Therefore, it was recommended that only the executive summaries of MEND reports be accessible through Internet.

Table 18: Technology Transfer

Completed Projects		**Spent($)**
5.1.1ac	Provincial Workshops	29k
5.3.1	Laurentian Database	35k
5.3.2	Expand Databases at Laurentian & UBC	12k
5.4.1	Acid Rock Drainage Technical Guide - version française	24k
5.5.1	Preliminary MEND Research Plan	25k
5.6.1	Second International Conference on the Abatement of Acidic Drainage	127k
5.6.2	Third International Conference on the Abatement of Acidic Drainage 15k	
5.8.1	Economic Evaluation of MEND-developed Technology	40k
5.2.1ac	Communications Plan - CIMM Lectures, Brochure	5k
5.2.1d	Communications Plan - Video on AMD/MEND	150k
6.1	New Ideas - Phase I	141k
6.2	New Ideas - Phase II	95k
Active Projects		**Budget($)**
5.4.2	AMD/ARD Handbook - Phase I	150k
5.7.1	MEND Newsletter	20k
5.6.3	Fourth International Conference on Acid Rock Drainage	80k
5.9	MEND Evaluation	80k
Recommended for 1996		
5.1.2	Workshops - additional funding	40k
5.7.2	CD-Rom Publication	40k
5.8.1	Education Initiative	5k
5.4.3	AMD/ARD Handbook - Phase II	100k
	Total	**1,213k**

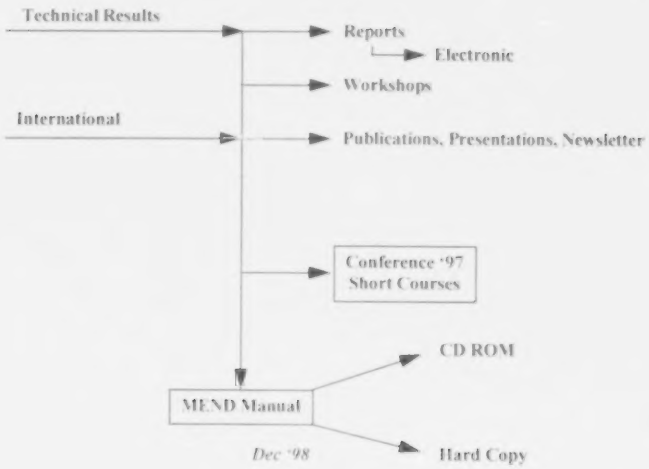
Other Initiatives

Report Distribution by MEND

Seminars, Conference Presentations, International Information Exchange

14: Technology Transfer 1995-1998

Comment: Figure 13 goes here



Appendix A
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N.B. Natural Resources and Energy

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Placer Dome Inc.

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M. Duc Vu
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Ministère des Ressources naturelles du Québec

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Mr. C. Weatherell	Coordinator, MEND Secretariat, CANMET
Ms. J. Zinck	Coordinator, MEND Secretariat, CANMET

Number	Titles
1.11.1	AMD from Waste Rock - Literature Review
1.12.1a	Compile AMD Prediction Data - DBARD
1.14.1	Field Evaluation Rock Hydrochemistry - Mine Doyon Phase I
1.14.2	Monitoring & Modelling AMD from Waste Rock: Mine Doyon Phase II
1.15.1	AMD from Open Pits - Equity Silver
1.16.1a	Evaluation of Predictive Techniques
1.16.1b	Manual of Chemical Evaluation Procedures
1.16.1c	Development of Static Evaluation Procedures
1.16.2a	Prediction Test Standard Material: Interlaboratory Program for Characterization of the ARD Standard Material NBM-1
1.17.1	Hydrogeochemical Investigation - Waite Amulet Reactive Tailings
1.19.1	Kinetic Test for Cinola Gold Project
1.21.1a	Evaluate RATAP BMT2 Capabilities
1.21.1b	Workshops of Modelling Techniques - Tailings
1.21.1c	Modelling of Reactive Tailings - Prepare RATAP User's Manual
1.22.1	Assessment of the Gas Transfer ANSTO Model at Heath Steele, Newcastle, N.B.
1.24.1	Development of Preliminary Modelling of Seepage Quality from Acid-generating Waste Rock Dumps.
1.25.1	Development of a Soil Atmosphere Flux Model for Design of Sulphide Tailings Cover Systems - Phase I
1.26.1	Development of a Modelling Methodology for Prediction of Seepage Quality from Acid-Generating Waste Rock - Phase I
1.31.1	Geochemical Study of Weathering Employing Secondary Ion Mass Spectrometry
1.32.1	Prediction and Prevention of Acid Rock Drainage - A Geological and Mineralogical Approach
1.41.1	International Waste Rock Modelling Workshop
1.41.2	ARD Waste Rock Monitoring Database
1.51.1	Quantitative Analyses of Chemical and Biological Kinetics
1.51.2	Non-linear Modelling of Chemical Kinetics for Acid Mine Drainage
2.11.1abc	Evaluation of Existing Underwater Disposal Sites
2.11.1d	Peer Review on the Subaqueous Disposal of Tailings

2.11.2a Literature Review Report: Possible Means of Evaluating the Biological Effects of Subaqueous Disposal of Mine Tailings

2.11.3abc Evaluation of Underwater Diposal Site - Anderson Lake

2.13.1 Flooding of Existing Tailings Sites: Quirke Lake

2.13.2abc Flooding of Existing Sites: Solbec Cupera

2.13.3 Flooding of Existing Sites: Falconbridge

2.14.1 Extablishing Vegetative Wetlands Over Tailings

2.20.1 Evaluation of Alternate Dry Covers Materials for the Prevention of Acid Mine Drainage from Tailings

2.21.1 Engineered Dry Covers for Tailings

2.21.2 Engineered Dry Covers for Tailings - Noranda

2.22.1 Assessment of Hardpan

2.23.1 Documentation of Disposal Methods for Tailings and Waste Rock (Draft Acid Rock Drainage Technical Guide)

2.23.2ab Hydrological and Geochemical Analysis of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines

2.23.2d Geochemical Evaluation of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines

2.23.3 Porous Envelope Disposal Method - Falconbridge

2.24.1 Vegetation Manual "Manual of Methods Used in the Revegetation of Reactive Sulphide Tailings Basins"

2.25.1ab Reclamation of Sulphide Tailings Using Municipal Solid Waste (MSW) Compost

2.25.2 Design of an Organic Barrier Using Wood Waste - East Sullivan

2.31.1a Dry Covers on Waste Rock - Heath Steele

2.32.1 Blending and Segregation of Waste Rock - Kutcho Creek

2.32.2a Co-Disposal of Tailings and Waste Rock in Cells - Les Mines Selbaie

2.32.3 Injection of Mine Tailings into a Waste Rock Pile as a Method to Control AMD - Literature Review

2.33.1 ARD Remediation Measures at Four Norwegian Mines

2.34.1 Use of Cementitious Covers to Control Acid Generation at Westmin's Myra Falls Mine - Shotcrete Field Trial

2.41.1a Electrochemical Oxidation/Passivation of Sulphides

2.44.1 Microbial Plugging of Mine Tailings to Reduce the Production of AMD

2.45.1a Separation of Sulphides from Mill Tailings

3.11.1a-c Treatment of Acidic Seepages Employing Wetland Ecology and Microbiology - Phases A, B and C

3.11.1d Treatment of Acidic Seeps Employing Wetland Microbiology (ARUM)

3.12.1 Assessment of Natural Wetlands Affected by Low pH/Metal Contaminated Seeps

3.12.2 Evaluation of Wetlands at Panel "A" Site

3.13.1a Passive Treatment of Small Seeps

Projects Completed Before 1995 Continued...

3.21.1a Metals Recovery from Acid Mine Drainage - Phase A

3.21.2a Removal of Metals from AMD - Chemical Treatment

3.22.1 Canada-Wide Survey of Acid Mine Drainage Characteristics

3.31 Use of Lime Sludges for Capping

3.32.1 Lime Treatment - Process Review and Sludge Stabilization

4.1.1 Field Methods Manual - Tailings

4.2.1 Decommissioning Criteria

4.3.1 Standard Reference Materials - Tailings

4.3.2 Standard Material - Net Neutralization Potential

4.5.1b Waste Rock Sampling Manual - Phase II

4.5.2 Field Sampling QA/QC

4.5.3 ARD Technical Guide - Monitoring Section

4.6.1 Assessment of Geophysical Techniques

4.6.2 Continous Monitoring of AMD - Literature Review

4.6.3 Remote Monitoring Techniques - Review

4.6.4 Piezocone Field Test

4.7.1 Optimum Sampling Frequence

4.7.2 Biological Monitoring of Acid Mine Drainage

4.7.3 Aquatic Invertebrate Monitoring

4.7.4 Acid Mine Drainage Sediment Monitoring

4.7.5 Ion Speciation

4.7.6 Paleolimnology Techniques

4.8.1 Monitoring of the Flooded Solbec Pit

4.8.2 Sediment Sampling Probe - Field Application

5.1.1a-c Provincial Workshops

5.3.1-2 Laurentian Database

5.4.1 Preliminary MEND Research Plan

5.5.1 Preliminary MEND Research Plan

5.6.1 Second International Conference on the Abatement of Acidic Drainage

5.6.2 Third International Conference on the Abatement of Acidic Drainage

5.8.1 Economic Evaluation of MEND-development Technology

PREDICTION

Project 1.11.1: AMD from Waste Rock - Literature Review
Expenditures: $50,000

A critical review of existing information on acid-generating waste rock was carried out as a basis for further work. Relevant information on theory, experiments, modelling and field studies were assessed for their validity and applicability. The impacts of various construction techniques on phase migration, solid, liquid, and gas, were assessed. Water movement and the migration of solids within rock piles were found to be dependant on hydraulic conductivity, hydraulic gradients, degree of saturation, and laminar versus turbulent flow. The migration of solids was defined in terms of internal migration and geotechnical failures, and gas transport, primarily through gaseous advection. The primary reactions were identified as: acid generation, which may be driven by abiotic and biological factors; acid neutralization; and metal leaching. Acid neutralization is a highly complex series of aqueous and mineral reactions. Speciation analyses were identified as useful but under-utilized. The parameters associated with the rate and extent of metal leaching were identified and discussed. This review is available as a MEND report.

Project 1.12.1a: Compile AMD Prediction Data - DBARD
Expenditures: $44,600

The objective of this project was to develop an acid mine drainage database of prediction test results by developing an accessible user-friendly database program, and adding available prediction data for mine projects in B.C. initiated subsequent to 1980. The data can then be analyzed for common trends and important differences, and recommendations made for improved approaches to pre-mine prediction. A computer database was developed through Morwijk Enterprises using dBase III plus. A comprehensive user's manual for Version 2.0 of the database was completed. The manual and database are available through the Chair for Mining and the Environment at the University of British Columbia. DBARD contains a significant quantity of prediction and other mine component characterization data for 119 mines in British Columbia. The database includes information on mines, mine component analyses, metal leach tests, static tests, and kinetic tests. Data are available on over 3,000 samples, including 3062 static test results, 1061 kinetic test cycle results, and metal analyses for 756 samples. The information input to date still only represents a small percentage of the huge quantity of ARD prediction data that have been generated over the past few years. Further data entry is therefore recommended both within and outside British Columbia. It is also recommended that the database be made

more generally available. A program to maintain and further develop the database is near completion (1.12.1b).

Project 1.14.1: **Field Evaluation Rock Hydrochemistry - Mine Doyon Phase I**

Expenditures: **$362,000**

Initial dump characterization of the 21 million tonne Mine Doyon waste rock pile in Québec was carried out through review and evaluation of all available site documentation. In-depth characterization (physical, chemical and hydrological) was done using: boreholes penetrating the entire thickness of the rock pile and into the bedrock; boreholes along the perimeter to sample groundwater; exploration pits to observe alteration phenomenon; and weir stations in the drainage ditches to measure water flow. An inventory and assessment was made of all granular material available for use as a (composite) dry cover. Although suitable materials were identified, differential compaction in the dump due to weathering does not favour the installation of a natural cover. Based on heat and mass balances it is estimated that 7000 tonnes of pyrite (< 1% of total) oxidize per year and that the amount of pyrite in the dump has not been significantly depleted. Temperature profiles indicate that oxidation is in a steady state and may be maintained for at least another 100 years. More detailed studies related to prediction were completed in 1994 (1.14.2). A comparison of mineralogical content with leachate chemistry will help understand reactions of leachate formation and transformation.

Project 1.14.2: **Monitoring & Modelling AMD from Waste Rock: Mine Doyon Phase II**

Expenditures: **$450,000**

The south dump at Mine Doyon afforded an excellent opportunity to study a waste rock dump in detail. Phase I (1.14.1) resulted in the instrumentation and detailed characterization of the south waste rock dump, as well as long-term prediction of acid generation potential using two independent methods. Phase II the monitoring program initiated in Phase I. From the information collected, geochemical, physical and hydrologic simulation capabilities were developed. Important physical parameters such as climatic data, temperature profiles within the dump, total discharge of acid drainage from collecting ditches and chemical composition of the effluents were monitored on a regular basis. Other parameters measured once or at regular intervals included: gas composition, piezometric levels, leachate composition in the unsaturated zone, infiltration rates, particle size and surface temperature. It is the first time that such a coherent and comprehensive set of parameters was assembled in a large waste rock dump.

Project 1.15.1: AMD from Open Pits - Equity Silver
Expenditures: $53,000

The overall objectives were to assess relative contributions of AMD sources in open pits and to develop an applicable computer model of such a system. All relevant information on water movement and chemistry on and within mine walls was reviewed. Acidic conditions appear to be at least partially due to unsaturated fractures. The rates of acid generation and neutralization on exposed pit walls of the Main Zone Pit at Equity Silver in British Columbia were determined using field studies and existing mine data. The importance of detailed baseline studies of groundwater prior to mining was emphasized. Metal leaching is strongly dependant on aqueous speciation and mineral solubility. A computer code, MINEWALL, was created to emulate open pits during operation and decommissioning and applied using site-specific information. In the case of Equity Silver, it was predicted that the flooded pit would return to neutral after the initial acid flush. MINEWALL has undergone preliminary verification but was not finalized for general use. Further development of MINEWALL was recently completed (1.15.2).

Project 1.16.1a: Evaluation of Predictive Techniques
Expenditures: $63,000

To predict the generation of acid mine drainage from mine wastes, several methods of varying complexity are available. These methods were evaluated to assess their reliability when applied to the field and to recommend those with the most promise for determining the potential for a material to generate acidic drainage. The following documented chemical prediction static and kinetic procedures were evaluated and compared: B.C. Research Initial test; Acid Base Accounting; Sulphur Ratio test; H_2O_2 for Pyrite Estimation; B.C. Research Confirmation test; Humidity Cell test; Shake Flask Weathering test; Soxhlet Extraction test; and Manometric Carbonate Pressure Analysis. In addition three more recently developed tests were evaluated: Net Acid Production test; Modified Biological Confirmation test; and Modified Acid Base Accounting. Evaluations were carried out by performing each procedure on eight tailings samples and four waste rock samples from Canadian mines. The advantages and limitations of each method are discussed. The documentation of the above procedures in a detailed user's manual format was recommended (1.16.1b).

Project 1.16.1b: Manual of Chemical Evaluation Procedures
Expenditures: $23,000

A user's guide was produced for the application of chemical evaluation procedures (identified in 1.16.1a) for the prediction of acid generation from mining wastes and related materials. The manual provides background information on acid generation from mine wastes and applicable references. An integrated approach to acid mine drainage prediction strategy is also outlined. Guidelines to the application of the individual prediction tests, details of procedures and associated considerations are addressed. The balance of the manual is devoted to the detailed descriptions of recommended and alternate chemical predictive procedures. Six static (short term) methods and five kinetic (longer term) methods are described. For each method, the applicability, objectives, advantages and disadvantages are discussed. The test principles, equipment and reagent requirements, test procedure interpretation and manner of result reporting are outlined in detail. To date there is no single chemical predictive method that is applicable to all waste materials and/or situations.

Project 1.16.1c: Development of Static Evaluation Procedures
Expenditures: $21,000

As part of the overall program to identify and evaluate techniques for predicting the potential for tailings and waste rock to produce contaminated run-off and seepage, further applicable static procedures were identified and assessed. Based on a review of the chemical literature four methods were ranked by parameters including: cost; rapidity and robustness; and selected for preliminary testing using samples of known mineralogical composition. The methods tested were: determination of sulphur as pyrrhotite and pyrite; field determination of sulphur as pyrite; modification of the conventional U.S. EPA neutralization potential procedure by filtration of leachate and addition of hydrogen peroxide; and determination of carbonates by metal analysis. The first procedure performed well but further development of the latter three was considered necessary. Methods to directly and quantitatively determine Ca and Mg carbonates are not commercially available and modification of the third procedure is recommended to address this problem. It was underlined that routine acid-base accounting should include a supporting mineralogical description to provide confidence in the predictive chemical results.

Project 1.16.2a: Prediction Test Standard Material: Interlaboratory Program for Characterization of the ARD Standard Material NBM-1

Expenditures: $20,000

This project was meant to extend the characterization of the standard material, NBM-1, for use as a standard material for acid rock drainage static prediction tests. The material, processed to minus 200 mesh, was bottled and sealed under nitrogen in foil pouches to protect against oxidation. The homogeneity with respect to iron and sulphur was confirmed and carbonate concentrations determined. Fourteen laboratories were selected on the basis of their experience with ARD methods and previous participation in other CCRMP projects. Participants were requested to follow the Sobek acid-base-accounting method for the determination of NNP using a specified fizz rating of "slight". The results showed a bimodel distribution and the mean of the NNP results was assigned provisional status. This value, 42 $\pm$ 9 tonnes $CaCO_3$/1000 tonnes, refers to the determination of NNP by the Sobek method with a fizz rating of slight. Values were also reported by the participating laboratories for paste pH, fizz test rating and NNP by other methods. The standard material produced, NBM-1, can be used for the very necessary method development and as a control standard for acid-base-accounting. The results are detailed in a report completed July 1994. Additional studies aimed at improving common ABA methods and producing subsequent standard reference materials are under development.

Project 1.17.1: Hydrogeochemical Investigation - Waite Amulet Reactive Tailings

Expenditures: $285,000

This multi-year hydrogeochemical baseline field study was designed to develop a better understanding of the hydrology and hydrogeochemistry occurring in acid-generating tailings ponds. The data were also collected to assess or refine existing predictive models (1.21.1a) and provide guidance in the development of new models and control techniques. Preliminary site reconnaissance along with piezometer installation and sampling of tailings and pore water allowed an assessment of the tailings and underlying hydrogeologic characteristics such as pore water chemistry, water table and tailings depth, mineralogy, hydraulic conductivity, direction of flow, and biological activity data. Further data collection completed the definition of the site hydrogeology. The unsaturated zone geochemistry under clay covered, directly vegetated and untreated sites and along the dam face was evaluated. Oxidation control options were defined. A water and metal balance for the tailings site was completed by monitoring precipitation, evaporation, and the flow and quality of the seepage at the face and the surface. The mineralogy of the unsaturated zone was defined and related to pore water chemistry using computer models. Oxygen diffusion versus depth into the tailings was determined. The study verified that the

most important control on pyrite oxidation is the availability of oxygen, which influences production of ferric iron and bacterial population density. Oxygen diffusion was considered horizontally as well as vertically.

Project 1.19.1: **Kinetic Test for Cinola Gold Project**
Expenditures: **$94,360**

This project involved the continuation of some of the long-term predictive testing of waste rock initiated for the Cinola Gold property in 1988 by City Resources. Specifically the objectives were to:

- characterize 6 years of acid generation trends from four on-site waste rock pads;
- evaluate a column study of mixing calcareous rock with waste rock;
- characterize material that has undergone over 3 years of humidity cell weathering; and
- compare and evaluate various predictive methods used.

Some of the more advanced and long term work in prediction of acid mine drainage has been conducted for the Cinola Gold Project (Queen Charlotte Islands, B.C.). These tests included: acid-base accounting (ABA); humidity cells to examine the long term acid production potential of marginal material (as defined by ABA); shake flasks to test short term acid release; column experiments to investigate the effect of limestone blending; and field waste rock piles to study the relationship between laboratory and field acid production. Leachate from the 4 waste rock pads were monitored through 1993 and material from one pad was sampled to analyze the extent of weathering. Of the 5 columns containing waste rock and varying percentages of limestone only the column with a Neutralization Potential/Acid Potential (NP/AP) ratio >1 generated pH-neutral water throughout the 5-year experiment. However, based on leachate data this column was also predicted to go acid. The columns were dismantled in late 1993.

Project 1.21.1a: **Evaluate RATAP.BMT2 Capabilities**
Expenditures: **$30,000**

Originating from work in the mid 1980's by CANMET, the Reactive Acid Tailings Assessment Program for Base Metal Mines (RATAP.BMT) was developed as a predictive modelling tool to: investigate the parameters which control sulphide mineral oxidation in tailings; simulate such acid generation; estimate acid generation potential in the long term; and evaluate control measures. The capabilities and limitations of the RATAP.BMT2 model were evaluated, including calibration of the model using Waite Amulet field data (1.17.1) and critical assessment of the concepts on which the model is based. Part of the data was used to calibrate the site dependent parameter estimates and the rest to verify the model both in the temporal and spatial sense. Modifications were made to the model when required. The modelled constituents included: temperature; pH; oxygen concentration with depth; and porewater concentration of sulphate, ferrous and ferric iron, dissolved copper and

zinc. The model was reviewed further (1.21.1b) and a manual generated (1.21.1c) for the current version of the program (RATAP.BMT3).

Project 1.21.1b: Workshops of Modelling Techniques - Tailings
Expenditures: $73,000

An international workshop was held on modelling of reactive tailings, to assess the current capabilities and the perceived requirements (industrial, regulatory). The workshop was held in Haliburton, Ontario on May 23 & 24, 1990. The workshop was attended by participants from Canada, Sweden, United States, and Australia, representatives from the mining industry, the consulting community, universities and various governmental departments. The presentations and discussions concentrated on the simulation model, RATAP.BMT2, capable of calculating the generation of sulphuric acid from reactive tailings. Other presentations provided a consulting engineering perspective, the industry perspective and the point of view of the regulatory agencies for the use of models. Finally, representatives of the United States, Sweden and Australia presented their assessment of current capabilities. The use of computer models capable of calculating the characteristics of reactive tailings and their impact on the environment was discussed. It was recommended that the RATAP.BMT2 model should be made available to potential users for evaluation before additional development of the model. It was also recommended that a user's manual should be prepared and made available with the model (1.21.1c).

Project 1.21.1c: Modelling of Reactive Tailings - Prepare RATAP User's Manual
Expenditures: $19,000

The mathematical model, Reactive Tailings Assessment Program (RATAP), was designed to predict, in the long-term, the quantity of acid generated by oxidation of pyrite in uranium mill tailings. This model was adapted to base metal tailings. At the international modelling workshop held in May 1990 (1.21.1b), it was recommended that the model be prepared for distribution to potential users. RATAP.BMT3 is a complex model with over 250 input parameters, not lending itself to easy use. Therefore a module to facilitate inputting initial condition data and a second module to facilitate the acquisition and display of output data from model simulations were developed. This combination provides a powerful user-friendly predictive tool. A user's manual was prepared for the software ensemble. As recommended, an overview document was prepared for RATAP.BMT3 to assist potential users. This was prepared, not as a separate document but as part of the input module, giving an overview of the models intended purpose and applications, estimated simulation capabilities, limitations, and expansion potential. The model and manual are being

distributed through the Canada Centre for Mineral and Energy Technology (CANMET).

Project 1.22.1: **Assessment of the Gas Transfer ANSTO Model at Heath Steele, Newcastle, N.B.**

Expenditures: **$145,000**

The objectives of this project were to develop an understanding of the processes governing pyrite oxidation rates in acid waste rock piles at Heath Steele, to quantify those processes, and to evaluate the effectiveness of the composite soil cover for acid waste rock management. The field component consisted of *in-situ* measurements of various parameters required by FIDHELM, namely the oxygen diffusion coefficient, air permeability, and thermal conductivity. These parameters were successfully measured and found to be in acceptable ranges when compared to other waste rock piles. The modelling component consisted of running FIDHELM employing the Heath Steele data collected during the field work. Gas transport mechanisms dominating the oxidation rates were identified using observed temperature and oxygen profiles in conjunction with FIDHELM simulations. A user's manual was also prepared. Numerical simulations indicate that gas transport is dominated by diffusion. These simulations also suggest that particular details in the oxygen profile measured at Heath Steele can be explained by the heterogeneity of the pile. Modelling of the waste rock pile with the soil cover in conjunction with field data indicate that the soil cover is effective to reduce the ingress of oxygen. Data collected to date agree with these simulations. A program of work to quantify the effect of advection by wind effects and to compare measured results with modelled results is recommended. Continuous monitoring of temperature and pore gas oxygen concentration profiles throughout the entire year should also be considered.

Project 1.24.1: **Development of Preliminary Modelling of Seepage Quality from Acid-generating Waste Rock Dumps.**

Expenditures: **$21,000**

The project was originally scoped to follow the complete development and abandonment of a 15 million tonne dump, over the course of four years. A variety of factors led to a much reduced scope of work, although it was recommended that the predictive modelling of AMD from waste rock be pursued. Collection and description of selected drill core samples from the Yukon (Curragh Resources) were carried out on site for dump material characterization. Key physical and chemical parameters were generally identified for the monitoring of reactive waste dumps. A conceptual model of the physical and geochemical nature of waste dumps was developed based on the existing literature and the incorporation of the parameters above. The development of such a model was recommended and would guide future assessment and design of instrumentation requirements for reactive waste rock dumps

(1.26.1). The complexity of the modelling effort and potential scope of the study has however, been recognised.

Project 1.25.1: Development of a Soil Atmosphere Flux Model for Design of Sulphide Tailings Cover Systems - Phase I

Expenditures: $55,800

The objective of this project was to develop a computer program to calculate the moisture fluxes between tailings, cover systems and the atmosphere based on routine climate data and soil properties. Carefully designed soil cover systems may be used as oxygen barriers in the control of acid mine drainage, the success of which will depend on climatic conditions and cover system properties. A mechanistic tailings-cover-atmosphere flux model for evaluating the flux boundary conditions and the soil-atmosphere interface was developed at the Universities of Manitoba and Saskatchewan. The mathematical derivation and formulation of the finite element solution for coupled heat and mass transfer in soil covers was successfully completed at the University of Saskatchewan. The Soil Atmosphere Flux model is compatible with PC/DOS computers. The program was tested by comparing its solution with those computed by other well-established methods. The University of Saskatchewan will continue with the development of the model to accommodate water flow and hydraulic effects under freezing conditions. Field data for this work will be collected from a mine site in British Columbia.

Project 1.26.1: Development of a Modelling Methodology for Prediction of Seepage Quality from Acid-Generating Waste Rock - Phase I

Expenditures: $90,000

The primary objective of this project was to develop a preliminary model based on the current state-of-the-art for predicting drainage water quality from waste rock dumps using existing theoretical and empirical relationships. The report, originally completed in 1993, was completely re-written by new authors to address numerous problematic issues. The revised report presents a critical discussion of mathematical models of acidic drainage from waste rock piles with an emphasis on engineering models. Development of these engineering models is generally by the "bottom up" or process specific approach. A more comprehensive approach is the "top down" methodology where one considers all of the influential variables in a rudimentary fashion. This style of model development should be employed to compliment the "bottom-up" approach. Current engineering models suffer from a lack of comprehensive documentation describing processes neglected during model development. Validation of engineering models is severely limited especially in the case of waste rock. This and other factors lends to limitations of current models that are not fully recognized by the mining industry. In the future, an appropriate combination of mathematical models and laboratory field studies need to be addressed to provide data for model calibration and to identify dominant geochemical processes. Overall, the development of ARD models is not limited by the ability to

generate and solve equations or to make elaborate computer programs but rather by a lack of fundamental understanding of key processes. Thus, fundamental research into individual processes needs to be continued.

Project 1.31.1: Geochemical Study of Weathering Employing Secondary Ion Mass Spectrometry

Expenditures: $98,600

The main project objective was to assess the applicability of Secondary Ion Mass Spectrometry (SIMS), Auger Electron Spectroscopy (AES), and X-Ray Photoelectron Spectroscopy (XPS), in defining compositional changes occurring in the upper angstroms of mineral surfaces as a result of weathering. Advantages and disadvantages of the three surface analytical techniques are presented. A parallel program involving surface analytical assessment of weathered and unweathered material, and conventional ARD prediction column tests were conducted. A direct comparison of naturally and artificially weathered surfaces to determine the predictive capacity of different humidity cell leaching regimes was not possible. The sulphide mineral size and content in the tailings and waste rock samples employed proved to be insufficient for the application of SIMS. Static and kinetic tests as well as whole rock, elemental and petrographic analyses were carried out on tailings from Echo Bay's Lupin Mine in the Northwest Territories and on waste rock obtained from Inco's Thompson Mine in northern Manitoba. Although direct comparison of naturally and artificially weathered material to assess predictive tests was not addressed, such a comparison may warrant further attention.

Project 1.32.1: Prediction and Prevention of Acid Rock Drainage - A Geological and Mineralogical Approach

Expenditures: $73,000

The three main objectives of this project were: to determine the tendency of major types of metallic sulphide deposits to generate acid; the relative oxidation rates of individual sulphide species in polysulphide assemblages; and the initial field measurements and laboratory analyses needed to asses the acid generation potential and expedite environmental impact assessment. Seven common types of metallic mineral deposits occurring in western Canada are ranked according to the potential for development of acid rock drainage (ARD). The deposit susceptibility is based largely on the net acid-generating potential of the prevalent mineral assemblages, the accessibility of the reacting minerals to weathering agents, and potential mediation by iron-oxidizing bacteria. A formula for assessing acid rock drainage potential based on field estimates of mineral abundance is suggested in the report. Detailed examination of the prevalent sulphides indicates the importance of trace element composition in affecting the stability of individual sulphides. It is therefore suggested that a general weathering sequence for the common sulphides may not exist except on a local scale. The report recommends that field geologists be trained to collect and interpret mineralogical and geological data and be involved in acid rock drainage assessment at every stage of a mining project. The report suggests a

practical checklist for field assessment of ARD potential during mineral exploration and tasks at various phases of a pre-mine development.

Project 1.41.1: **International Waste Rock Modelling Workshop**
Expenditures: **$7,770**

A three day international workshop on modelling the generation and transport of acid rock drainage from mining waste rock was hosted by MEND in late September 1992. Its purpose was to focus research and development of modelling capabilities for waste rock dumps to the needs and requirements of users by identifying current (international) capabilities and shortcomings, and industry/regulatory requirements. It was suggested that a useable model should incorporate the following: oxygen and heat transport; solute movement and hydrology; and geochemistry. Oxygen and heat transport can be modelled although additional field assessment of relevant parameters was recommended. The area of solute transport and hydrology under mainly unsaturated conditions is less advanced. The geochemical processes are considered the most difficult, and in some case's simulation may not be possible. Among other actions, a critical review of the key geochemical processes and associated current modelling capabilities (1.42.1) was recommended to assess the potential for incorporation of geochemistry into the overall predictive capacity. The workshop proceedings are available through the MEND secretariat.

Project 1.41.2: **ARD Waste Rock Monitoring Database**
Expenditures: **$22,000**

The objective of the project was to develop a database to provide an overview of all significant ongoing and past field monitoring studies of acid or potentially acid generating waste rock dumps in Canada and internationally. Following a review of available data access systems, a PC Windows[1] based application (Paradox for Windows[1]) was chosen for the database. The database was constructed with five tables to contain information as follows:

- general mine information
    - general waste rock dump characterization
    - waste rock dump material characterization
    - monitoring program details, and
    - data access.

Details of the monitoring program include the parameters measured, the methods and instrumentation used, the temporal and spatial extent of measurements, and any data analysis or modelling done as well as a summary of any conclusions drawn. As part of the gathering of information, a questionnaire was sent to solicit waste rock dump information and sent to over seventy contacts in Canada and internationally. Data was obtained for 31 mines and 45 associated waste dumps from Canada, Australia and Sweden. The data is available in a database format for Paradox for Windows[1], Microsoft Excel[1] spreadsheets and text delimited files. ([1] Copyright @ 1994

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Project 1.51.1 **Quantitative Analyses of Chemical and Biological Kinetics**
Expenditures: **$11,750**

The primary objective of the project was to provide a quantitative analysis of the interrelated elementary chemical and biological processes that together are responsible for pyrite oxidation and acid rock drainage. A secondary objective was to determine whether the coupled chemical reactions involved in oxidation of pyrite lead to irregular or chaotic changes of products of the reactions responsible for acid rock drainage. The final report (released June 1994) reviews and critically analyzes several experimental and theoretical results on chemical, physical and biological aspects of pyrite oxidation. Based on available information a kinetic model in the form of coupled non-linear ordinary differential equations were constructed for the coupled chemical reactions responsible for ARD. The model is based on small-scale experimental data for pure pyrite. Computer simulations for the concentrations of H^+, Fe^{2+}, Fe^{3+}, and SO_4^{2-} were performed for different values of the controlling chemical and physical parameters. The model does not include transport processes. Biological activity associated with pyrite oxidation is considered with respect to temperature, pH, available oxygen and other oxidants. Kinetic equations for biological activity are proposed for the first time. The set of non-linear kinetic equations considered in the study for the chemical reactions involved in pyrite oxidation does not appear to produce chaotic behaviour or other types of chemical oscillations. Application of this methodology to developing a waste rock model is currently being pursued (1.28.1a,b)

Project 1.51.2: **Non-linear Modelling of Chemical Kinetics for Acid Mine Drainage**
Expenditures: **$34,550**

The complexity of the chemical reactions involved in ARD precludes an easy and simple approach to the prediction of ARD generation. The chemical processes are not only strongly dependent on external conditions and the geology of the terrain but, they also involve feedback loops making the problem inherently non-linear. This project was chiefly concerned with the modelling of non-linear kinetics of the chemical reactions present in both acid production and acid neutralization that are associated with the ARD process. An extensive literature survey encompassing both geochemical analyses regarding AMD and the relevant aspects of non-linear chemical kinetics was conducted. The report looks at the chemical reactions involved in the chemical oxidation of pyrite (i.e. type, activation energy, rate, and thermodynamics). A theoretical mathematical model, rather than empirical, has been used to explore a wide range of extreme situations to uncover non-trivial behaviour. Sulphide chemical oxidation does intrinsically produce variability in results. Therefore based on chemistry alone, it is possible to predict ARD outcomes. Irregular variations in

chemical species concentrations are observed and this irregular behaviour seems to be mainly affected by the porosity of the medium and the presence of non-zero flow rates of oxygen and water. The report indicates that the effect of physical processes may have a greater effect on the predictability of acid rock drainage problems.

Project 2.11.1a-c: Evaluation of Existing Underwater Disposal Sites
Expenditures: a: $220,000 b: $136,000 c: $67,625

The objective of this project was to evaluate the effectiveness of underwater disposal of reactive wastes by evaluating representative existing sites, examining the impacts which result when in-lake disposal systems are used, and recommending guideline for the safe underwater disposal of tailings. Initially (2.11.1a), all known Canadian sites were documented and water quality results were obtained from existing sources (1988/89). Field surveys were done on 4 sites during the summer of 1989 (Buttle and Benson Lakes in B.C., Anderson and Mandy Lakes in Manitoba). Geochemical assessments were conducted at Anderson and Mandy Lakes in Manitoba in 1990 (2.11.1b). Two projects were completed on Benson Lake in 1991-1992. The first project focused on the chemical and biological aspects of changes in Benson Lake following subaqueous tailings disposal. The second project used Keogh Lake, a pristine, hydrographically similar "control lake" to permit geochemical comparison between lakes with tailings and without tailings (2.11.1c).

Project 2.11.1d: Peer Review on the Subaqueous Disposal of Tailings
Expenditures: $34,350

At the request of the MEND Board of Directors, a scientific and technical review of the work completed to 1992 was carried out (2.11.1d). The objectives of this project were to provide technical and scientific assessment of MEND studies on subaqueous disposal of tailings, and to outline additional requirements necessary for the MEND studies to maintain a credible scientific approach. The Peer Review was carried out by The Rawson Academy of Aquatic Science with the aid of highly qualified and experienced scientists, each a specialist in one or more fields of science dealing with aquatic ecosystems. The reviewers agreed that the work on the three lakes reviewed, Mandy, Anderson and Buttle (Benson was not reviewed because work there was not complete) was well done. The review identified key areas that are lacking in information. For instance, the studies of background limnologies for the lakes were not suitable to present to regulatory personnel, the seasonal and yearly changes that occur in the water column loadings would have to be addressed and the field experiment for metal flux measurements, although well done, does not assess the quantitative fluxes which are considered important. Some additional literature reviews (e.g. metal toxicology) and a complete program for documenting QA/QC were suggested and the definition of the types of additional field data (e.g. geochemical) and methods for data collection were presented. Additional work to develop a more complete understanding of the sites under study was recommended.

Project 2.11.2a: Literature Review Report: Possible Means of Evaluating the Biological Effects of Subaqueous Disposal of Mine Tailings
Expenditures: $16,300

One of the recommendations made in the Peer Review (2.11.1d) was that "selective and additional literature reviews" be undertaken on the biological uptake of metals, their bioaccumulation, and their possible toxic effects on aquatic organisms. The objective of this study was to respond to this recommendation. Given the extensive literature available on metal-organism interaction, the focus was on the possible biological effects of subaqueous disposal of mine tailings. The basic premise has been that mine tailings and their constituent metals, may affect aquatic life in two ways: indirectly (i.e. by leaching of the metals into the ambient water, followed by their assimilation from the aqueous state), and directly (e.g. in microfauna, by ingestion of the tailings and assimilation of the metals). Both routes were considered. This review identifies promising geochemical and ecotoxicological approaches that might be used to monitor the biological effects of the subaqueous disposal of reactive mine tailings.

Project 2.11.3abc: Evaluation of Underwater Disposal Site - Anderson Lake
Expenditures: $410,000

Specific comments from the Peer Review (2.11.1d) focused on the requirements for additional work on Quality Assurance/Quality Control. All phases of the program from sampling to analysis were addressed to yield statistically valid results. Two campaigns were completed at Anderson, late winter 1993 (2.11.3a) and mid-August 1993 (2.11.3b), which included water column sampling, sediment cores, and peepers, as well as measurements of field parameters. Results from both campaigns, particularly the high-resolution water column sampling, confirmed the findings from earlier studies that the sediments were acting as a sink rather than a source for metals in the water column. In 1994 an assessment of the mine-related inputs to Anderson Lake was carried out (2.11.3c) to determine as much as possible the extent of relationship between the various discharges and observed historical changes in lake chemistry. The final report, which includes the two sampling campaign, the review of historical data, and the 1995 program (2.11.3d) will be available in 1996.

Project 2.13.1: Flooding of Existing Tailings Sites - Quirke Lake
Expenditures: $835,000

A joint project between Rio Algom and CANMET to assess the feasibility of flooding the existing Quirke tailings site was started in 1989. The work included site characterization, laboratory column lysimeter studies and a large-scale field demonstration cell (65 hectares). Laboratory column leaching studies demonstrated that a shallow water cover, approximately 0.5m in depth, was very effective in reducing acid generation. In comparison to unsaturated coarse tailings, total productions of acidity, sulphate and iron were reduced by factors of approximately 300, 200 and 950 respectivelywhen the tailings were flooded and maintained under a shallow water cover. A 65 hectare flooded field demonstration and test site was also prepared which has been underwater since November 1992. The performance of the water cover is being evaluated by monitoring the flooded site for its hydrological parameters, surface and porewater chemistry, and sediment characteristics. Reports for both laboratory and field components will be available in 1996.

Project 2.13.2abc: Flooding of Existing Sites - Solbec Cupra
Expenditures: $291,000

The key conclusions from the overview report (2.13.2a) on the work carried out at the Solbec Cupra tailings impoundment since 1989 are that: flooding under a shallow water cover inhibits further oxidation of acidic tailings and prevents the process in non-oxidized tailings; the inhibitive effect is progressive, and porewater in oxidized tailings remains acid for a certain time before reaching a neutral level; and, neutralization of the oxidized layer by adding and mixing finely crushed limestone prior to flooding has the effect of rapidly stopping the oxidation process and raising and maintaining porewater pH to neutral levels. In 2.13.2b the minimum depth of water required to prevent resuspension of solid particles through wind action was found to be 1.34m. However, with a layer of sand (i.e. diffusion barrier) at the tailings/water interface the required level may be reduced to 0.7m. In another related study on the microbiological factors (2.13.2c) it was found that there was no bacterial activity in the 1989 flooded lysimeters. However, a large bacterial population was found outside the experimental basins in the oxidized tailings.

2.13.3: Flooding of Existing Sites - Falconbridge
Expenditures: $170,000

Studies have been conducted on Falconbridge's 90 hectare "New Tailings" site to evaluate the feasibility and control provided by a shallow water cover on high sulphur (40 to 50% pyrrhotite) tailings. **The pond consists of two areas divided with a low berm. Low sulphur (1%), low permeability tailings slimes partially cover the upper area.** After four years of abandonment, without a water cover, the slimes covered tailings area did not turn acidic. The water chemistry in the tailings and the gas compositions in the vadose zone indicated that oxidation of pyrrhotite in the tailings is ongoing. A second component of this project was the development of a computer model (WATAIL) to assist in the prediction of acid and metal releases before and after flooding. Work has begun on dredging the lower tailings area to get the remaining tailings underwater. A low head dam to flood back the upper area is planned. Monitoring of the flooded site will continue and the information generated will be made available to MEND.

Project 2.14.1: Establishing Vegetative Wetlands over Tailings
Expenditures: $30,000

The objective of this project was to develop a technique for the reclamation of high iron sulphur tailings by establishing a marshland or perched water table above the tailings. The project was initiated in 1986, when a total of 9 test cells with different surface covers and amendments were constructed at Falconbridge's Fault Lake tailings site. The covers were kept wet and the porewater quality and metal loading of the unoxidized tailings were monitored for three field seasons. Two important recommendations resulted from this study. First, to establish a marshland or perched water table above the tailing one must understand the hydrology of the site to define the water table and the groundwater fluctuations. Second, one must determine the hydraulic conductivity and gas permeability of the tailings. In these trials, coarse tailings resulted in high water/gas permeabilities and a perched water table could not be maintained without continuous irrigation.

Project 2.20.1: Evaluation of Alternate Dry Cover Materials for the Prevention of Acid Mine Drainage from Tailings

Expenditures: $55,000

The objective of the study was to prepare a ranking of the potential alternate cover materials that could be considered for further dry covers research. The theoretical concept of dry covers was reviewed and the barriers classified as oxygen barriers (moisture retaining), oxygen consuming, or reaction inhibiting. Potential barrier materials were identified through a technical literature search; a literature review focused on forest product industry wastes, and a search for potential materials that may be obtained from municipal and industrial wastes. A short list of potential materials was developed applying a two-stage screening process which takes technical aspects, cost, and practical application into consideration. Potential barrier materials considered to provide broadly based (country wide) benefit and a good likelihood for success are listed. Potential materials given a high priority for future research include natural soils, modified soils, desulphurized tailings, tailings slimes, wood waste, and paper mill sludge. Materials given a lower priority for future research include peat, waxes, ashes, and phosphate. Available barrier materials not requiring additional research are limestone (mixed into the tailings mass), and synthetic liners.

Project: 2.21.1: Engineered Dry Covers for Tailings

Expenditures: $216 000

The objective was to develop laboratory and computer methodologies for testing, designing, placing and evaluating the effectiveness of engineered soil covers for reactive sulphide wastes. Practical concepts were proposed for designing high performance soil covers using locally available natural materials. Critical material properties required for design and prediction of performance were identified and these were obtained using specially designed laboratory columns. A computer model describing oxygen diffusion in soil covers was also developed and was used in demonstration column work for different cover projects (Waite Amulet (2.21.2) and Heath Steele (2.31.1)). These evaluation techniques and standardized laboratory procedures will permit the testing of candidate soils from which the full-scale results can be modelled and predicted.

Project 2.21.2: Engineered Dry Covers for Tailings - Noranda
Expenditures: $532,800

The objective of the project was to design, construct and evaluate the effectiveness of engineered soil covers in preventing and controlling acid generation in reactive mine tailings. A total of four test plots were constructed at the Waite Amulet tailings site, consisting of two composite soil covers with a compacted clay layer sandwiched between a fine and coarse sand layer, one geomembrane cover and a control (tailings without cover). These were instrumented to measure gaseous oxygen concentrations, water content, suction, temperature and porewater quality at various depths. Coincidental with the field work, six columns were installed in the laboratory to simulate soil-covered and uncovered tailings. Gaseous oxygen concentrations, water content, temperature and drainage water quality were measured over time.

Results of the laboratory, field and modelling studies indicated that the oxygen flux was reduced by 91 to 99% by the soil cover. Monitoring of acid fluxes over time suggested that the rate of acid production decreased with time. Hydrologic modelling indicated that water percolation through the cover was about 4% of precipitation compared to 6% in the field tests (80% reduction). The effects of freeze-thaw on the integrity of the compacted clay layer showed that freezing and thawing did not adversely affect the cover.

Project 2.22.1: Assessment of Hardpan
Expenditures: $100,500

The project was designed to characterize the mineralogy of hardpan and to assess if it could be stabilized and used as an oxygen barrier. Petrographic studies and permeability tests were conducted on selected hardpan samples from four Manitoba tailings sites. The general properties of hardpan were initially found to be encouraging as a relatively impervious and resistant zone was observed. Weathering and seasonal frost, however, tended to break down the hardpan, resulting in a fractured, softened zone which possessed only moderate resistance to infiltration and continuous oxidation. As a result, serious doubts remained concerning the use of hardpan to control the acid generation process. Also, no suitable method of artificially creating hardpan was determined.

Project 2.23.1 Documentation of Disposal Methods for Tailings and Waste Rock (Draft Acid Rock Drainage Technical Guide)

Expenditures: $75,000

A comprehensive manual was prepared which provides an introduction to acid rock drainage (ARD) and direction on how best to deal with the problem. Techniques are discussed with respect to the handling of waste rock, tailings, open pits and underground workings. Current approaches in other parts of Canada and the world are also described. The manual was prepared as a "how to" document and is being distributed in loose leaf binder format so that the manual can be easily updated in the future.

Project 2.23.2ab: Hydrogeological and Geochemical Analysis of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines

Expenditures: $155,700

The objective of this two-year study was to measure the hydraulic properties of the TTD system to analyse their effects on the long term impacts to the environment. A field evaluation of the principal components of the site hydrology for verification of the high moisture retention of the TTD method was completed. The field program included measurements of moisture content, hydraulic head, water table elevation, hydraulic conductivity, precipitation, pan evaporation and evaporation. Porewater was sampled and analysed for major metal and ion concentrations. The result from measured physical characteristics inferred the presence of a significant capillary fringe above the water table. The analysis of porewater indicated that sulphide oxidation is occurring. However, low porewater velocities and near-surface saturated conditions will ensure that contaminants released to the environment will remain at the present rates, which is low, even after mine closure. The study suggests that the TTD method seems to be advantageous because of the low dissolved metal fluxes to the environment.

Project 2.23.2d: Geochemical Evaluation of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines

Expenditures: $260,000

In this study, the hydrogeological flow system, the geochemical interactions and the influence of discharging tailings pore water on the quality of run off from the tailings during storm events was reviewed. The study revealed four distinct geochemical zones; with the bottom zone with high alkalinity and low dissolved metals; the zone above the bottom; displaying high alkalinity with characteristics similar to original mill discharge water; a zone above this layer where jarosite, a component of the Kidd tailings has affected the pore water. The surface layer exhibited limited oxidation to approximately 0.5 m in depth. In the case of the jarosite being added to the tailings, the neutral pH and low E_H provides a thermodynamically unstable environment to the jarosite material, but it has subsequently been found that only 10% of the neutralization capacity of the tailings would be consumed in the jarosite decomposition process (1% of the carbonates). The hydraulic conductivity in the cone has been reported to be quite low (10^{-8} m/s). Storm events studied at the site indicate that tailings pore water comprises between 0 and 23% of the total stream flow. The low effective specific yield of the thickened tailings causes a rapid water table rise during rainfall events. The greatest potential for discharge of significant solutes from pore water occurs while the water table is at or near surface. The geochemical - hydrogeological, and hydrological studies are confirming that the TTD method has benefits in terms of controlling acidic drainage.

Project 2.23.3: Porous Envelope Disposal Method - Falconbridge

Expenditures: $207,000

A porous envelope effect may occur in groundwater systems when mine tailings of low permeability are placed within high-permeability soils. If the permeability contrast between the tailings and the natural soil is sufficiently large, groundwater will flow around the tailings mass rather than through it, minimizing metal leaching. Sulphide oxidation products from the tailings are diluted and neutralized by the flow of groundwater. Sulphide oxidation was detected at the Fault Lake tailings site, but geochemical processes were attenuating acidity and metals in the tailings mass. Mineralogical analysis and acid-base accounting indicated that the carbonate mineral reserves were available for short term neutralization of acid and silicate mineral were plentiful for long term buffering. High oxidation rates were observed since deposition was discontinued in 1978, yet little impact was observed in the groundwater due to the porous envelope effect. Attenuation of the sulphide oxidation products is achieved primarily through the neutralization potential (NP) of the

tailings, with the porous envelope effect acting in areas of depleted NP and where preferential flow was measured.

Project 2.24.1: Vegetation Manual "Manual of Methods used in the Revegetation of Reactive Sulphide Tailings Basins"

Expenditures: $33,500

The manual provides a comprehensive description of procedures for preparation, neutralization, seeding and follow-up maintenance, if required, for revegetation of reactive sulphide tailings disposal areas in Canada. It describes and illustrates some of the more common agricultural equipment and fundamental, basic techniques required to prepare, seed and maintain mine waste areas revegetated. Case histories are appended that outline reclamation programs carried out at several Canadian mines including Falconbridge, INCO and Noranda.

Project 2.25.1ab: Reclamation of Sulphide Tailings Using Municipal Solid Waste (MSW) Compost

Expenditures: $ 86,000

The objective of this study was to conduct a laboratory investigation to determine the optimal cover design, and safety, for using MSW as a permanent solution in an abandonment strategy for sulphide tailings. Phase I was a literature review of what is known about the physical and chemical characteristics of MSW compost and other organic materials (2.25.1a). The conclusions of the survey led to Phase II - laboratory column experiments. The experimental work showed that a cover layer of MSW compost can be of benefit in the reclamation of oxidized tailings. There is strong evidence of a reversal of AMD processes in the oxidized tailings as shown by the formation of iron sulphide precipitate near the cover layer - tailings interface. The conclusions were based on a relatively short term laboratory experiment and this study should be seen as a preliminary look at compost cover layers and their design as a tailings AMD solution (2.25.1b). Comprehensive, long term laboratory pilot scale work was recommended and implemented (2.25.3) to follow up on the potential benefits that were identified for organic type materials.

Project 2.25.2: Design of an Organic Barrier Using Wood Waste - East Sullivan
Expenditures: $210,000

The objective was to evaluate the effect of wood waste (bark, pulpwood and sawdust) covers on the process of tailings acidification. The ligneous wastes can form an effective barrier while conserving a high level of humidity and consuming some of the available oxygen. Six 20m X 20m experimental test plots, with monitoring instrumentation, were constructed on the site. Sampling campaigns for the solids (e.g. wood waste), gas and liquid phases were carried out over a three-year period. The analysis of interstitial gases in a layer of wood chips 100cm thick covering mine tailings demonstrated that this material effectively blocks access to oxygen which could oxidize underlying sulphates, as demonstrated by the fact that methane is generated. Monitoring results on the gas concentrations in the wood wastes have shown that the oxygen concentration dropped from 16.1% to less than 1.5% at a depth of 70cm and CO_2 levels increased from 8.2% to 50.8%. The high permeability of the material and the 1m thickness of the cover should prevent methane gas pockets and spontaneous combustion. High concentrations were found in the test cell containing sewage sludge which probably filled the voids and prevented the methane from escaping.

Project 2.31.1a: Dry Covers on Waste Rock - Heath Steele
Expenditures: $312,000

Acidic drainage generation in waste rock poses a much different problem from that of tailings because of the huge difference in the particle sizes of the waste material. Waste rock piles contain large voids which allow water and air to freely penetrate the pile. These conditions promote accelerated bacterial and chemical reactions. The objective of the project was to evaluate the effectiveness of engineered natural covers for reactive sulphide waste rock at the Heath Steele mine site. Locally available cover materials were sampled and characterized according to standard soil properties. A column apparatus was used to measure the rate of oxygen diffusion through potential cover materials (2.21.1). Based on the results of the laboratory testing a practical, composite cover was designed using native materials. In order to confirm the effectiveness of the proposed cover it was recommended that the cover be field tested (2.31.1b).

Project 2.32.1 **Blending and Segregation of Waste Rock - Kutcho Creek**
Expenditures: **$ 140,000**

The objective was to evaluate, through laboratory and field analysis, the effectiveness of segregating and blending acid-generating waste rock and alkaline material as a method of preventing or controlling AMD. Acid-base accounting tests were used to identify the materials. Humidity cell tests composed of blended ratios demonstrated that the rate of acid generation was reduced. Results from the test pads were not as conclusive as the laboratory results. It was discovered that leachate quality was dependent upon flushing rates as opposed to the actual acid generation rate. Long term predictions, based on the results from the humidity cell test work, showed that the neutralizing potential could be consumed in as early as 100 weeks with acidic conditions continuing until all sulphides were oxidized. A separate analysis determined that the costs associated with blending large amounts of waste materials in a full scale waste dump would be excessive. Based on these predictions, blending of Kutcho waste rock, even at 1:1, would not be a viable option.

Project 2.32.2a **Co-Disposal of Tailings and Waste Rock in Cells - Les Mines Selbaie**
Expenditures: **$96,000**

The objective of the project was to evaluate the concept of co-disposing reactive sulphide waste rock with non-reactive tailings in basins to minimize acidic drainage from the waste rock. The design seeks to create saturated conditions in the reactive waste and minimize groundwater flow in the basin. Phase (a) consisted of field reconnaissance, characterization of both tailings and waste rock and potential basin construction materials, and a preliminary geotechnical design of the basin. The prediction tests carried out on the tailings materials indicated that the tailings are likely to generate acid. The project was based on the concept of co-disposing acid-generating waste rock with neutral tailings. Since the tailings are likely to be acid producers, the final design of the basin was changed to rely on low permeability dykes to maintain saturated conditions in the waste rock and tailings. This was not the original concept and no follow-up work was recommended.

Project 2.32.3 Injection of Mine Tailings into a Waste Rock Pile as a Method to Control AMD - Literature Review

Expenditures: $9,900

The objective of this project was to evaluate the feasibility of injecting mine tailings into a waste rock pile to reduce porosity and permeability and increase the degree of saturation of the pile as a method to control acid mine drainage. The literature review revealed that the injection concept is a unique method that has not been tried before. The review centred on possible analogous research that could be applied (e.g. hydraulic backfill, flow transport modelling, cementing additives, physical parameters, etc.) to develop the injection process which has the advantage of using a waste product. Based on the literature review, a laboratory program was developed and proposed (budget $375k). Following a review, MEND recommended that a $100k "proof of concept" study be undertaken by the proponent to complete a technical and economic feasibility study of the injection process. The requested amended proposal was never submitted to MEND and no further work is planned.

Project 2.33.1 ARD Remediation Measures at Four Norwegian Mines

Expenditures: $38,500

The project was undertaken to provide a transfer of information of full-scale remediation measures used at four sulphide mines in Norway. The study addresses operational difficulties, procedures, results and costs of natural sulphate reduction (Lokken mine), natural convection as an evaporative treatment process (Killingdal mine), geomembrane covers (Kjoli mine) and underwater disposal (Skorovas mine). The final report makes conclusions and recommendations about the remediation methods used at the four sites.

Project 2.34.1 Use of Cementitious Covers to Control Acid Generation at Westmin's Myra Falls Mine - Shotcrete Field Trial

Expenditures: $130,000

The primary purpose was to evaluate the long term stability of a large scale shotcrete cover in the field environment. The shotcrete test was conducted on a 3500 square metre area of the main waste rock pile at Westmin's Myra Falls site. A wet-mix shotcrete application was applied using a remotely controlled robotic arm mounted on a rubber-wheeled carrier. Mixes utilizing imported aggregate and mine tailings were tested. The results of the field trial indicated that the robotic application system produced a good quality application with high rates of productivity and uniform placement. Visual inspection through 1995 indicated that the overall durability of the material was good. Some plastic shrinkage cracks were observed in the shotcrete immediately after application due to the high rate of evaporation before initial set. The result of the laboratory testing indicated that the compressive strength of the mixtures exceeded the design objective. Some reduction in compressive strength was observed in the tailings mix after 400 days which may be the result of oxidation of the sulphide minerals in the tailings material. An assessment of the cost of the shotcrete application indicated that the transport of the aggregate to the mine site is the largest cost component.

Project 2.41.1a: Electrochemical Oxidation/Passivation of Sulphides

Expenditures: $60,000

The objective was to develop electrochemical methods for the prevention of atmospheric oxidation, acid generation and leaching of sulphide tailings. In this project, it was established that a passive iron oxide film grown on pyrite/pyrrhotite can protect the substrate from oxidation on exposure to air and hence prevent acid generation. It was also shown that a bed of pyrrhotite rich tailings can be converted into a hardpan by a cathodic treatment followed by exposure to air under moist conditions. Six weeks after switching the current off, the bed automatically consolidated into a hardpan with some expansion. The solution percolating through this bed in the earlier stage of hardening had a pH of 5.5 and the iron concentration was lowered to natural equilibrium values. Following a progress review meeting, it was recommended that the project not continue to larger scale tests. However, the concept of in situ formation of synthetic hardpan by surface chemical treatment, briefly presented in Phase I, was recommended to the New Ideas Task Force for consideration. An additional project was completed under New Ideas but did not show economic potential.

Project 2.44.1: Microbial Plugging of Mine Tailings to Reduce the Production of AMD
Expenditures: $100,000

The objective of the project was to evaluate, at a laboratory scale, the microbial plugging technology as a method of reducing the production of AMD. The project involved the use of starved indigenous microorganisms called ultramicrobacteria's (UMB's) which, when exposed to nutrients, reproduce and excrete polymers. The polymers fill the void spaces in the tailings, effectively creating a microbial plug capable of reducing the penetration of both oxygen and water. The results of the study were that: it was not demonstrated that a microbial cap could significantly reduce the permeability of the tailings over long periods of time; a decrease of the oxygen penetration was observed for the columns that received nutrients; an increase in pH was observed for all of the permeates from the columns that received nutrients; and addition of UMB's to the tailings was not necessary because native strains were present in the tailings. It was also noted that although a reduction in permeability was not observed in the experiments, it is possible that in fine textural tailings, a significant reduction in water permeability would be expected. No follow-up work was recommended.

Project 2.45.1a: Separation of Sulphides from Mill Tailings
Expenditures: $75,000

A review of various mineral processing separation techniques and their application for the removal of sulphides from mill tailings was completed. The project included a descriptive review of the operating principles of each technology as well as bench scale testing of several processing methods. Four mill tailings samples were obtained from three operating mines. These were characterized to determine their acid generating potential and were processed by various separation techniques. The samples were then re-analysed to determine the effectiveness of the sulphide separation. The characterizations included humidity cell tests, acid base accounting, ICP analysis and a mineralogical evaluation. Conceptual flow sheets were developed for each sample and the cost of implementation estimated. The results of the study proved that the gravity techniques tested were incapable of separating the sulphides sufficiently to remove the acid generating capability of the tailings. This is likely due to the fact that the sulphide fractions tend to be concentrated in the finest size

fractions of the tailings. The separation technique that was successful in removing most of the acid generating potential of the tailings samples was direct flotation.

TREATMENT

Project 3.11.1a-c: Treatment of Acidic Seepages Employing Wetland Ecology and Microbiology - Phases A, B and C
Expenditures: $679,000

This project was designed to investigate the use of microbiology and ecology of wetlands to reduce acid mine drainage. A major objective was to develop design parameters for the Acid Reduction Using Microbiology (ARUM) process. The project had the following phases: a), Conduct microbiological nutrient requirements and cellulose degradation studies in the laboratory, and set up field systems at Elliot Lake and Copper Cliff, Ontario; b), Microbiological and water quality monitoring and conduct process capability tests; c), Monitor system performance and make final adjustments; and d), Monitor and establish performance criteria for operating systems.

The key results related to water quality; significant alkalinity was created (27 kg/tonne of water) and the heavy metals were precipitated as sulphides. However, the system appeared to be capable of handling only low flows, less than 3 to 5 litres/minute. At the very low flow of 1 litre/minute, very good water quality had been produced. The Treatment committee carefully reviewed the results achieved to the end of 1991 and recommended that the final year's monitoring and determination of performance criteria be completed (3.11.1d).

Project 3.11.1d: Treatment of Acidic Seeps Employing Wetland Microbiology (ARUM)
Expenditures: $80,000

The final report entitled: "Treatment of Acidic Seepages Using Wetland Ecology and Microbiology: Overall Program Assessment" summarized the field observations and measurements over 4 years in the field at Sudbury, determined the operating parameters for the ARUM system, produced design criteria and conceptual design, and estimated operating costs. The results showed that some very good water quality results had been achieved at a flow rate of 1 litre/minute. However, it appears that the system is not suitable for final treatment of large flows, but rather is applicable for pre-treatment in advance of an engineered treatment system. This will reduce costs by generating alkalinity and by precipitation of some of the metals. It could also be used for small seeps, or part of a package involving dry covers to reduce effluent flow rates. Considerable research and process development has been done on passive systems for treatment of AMD. The studies, including the ARUM process, have demonstrated that the use of passive systems to treat acidic seepages is

technically feasible but that the performance and the applicability of these systems remain uncertain. The main problems are low capacity, fouling and high retention times needed.

Project 3.12.1: Assessment of Natural Wetlands Affected by Low pH / Metal Contaminated Seeps

Expenditures: $40,000

The study examined natural wetlands near six base metal mines in Eastern Canada for evidence of biological mitigation of acidic drainage. Potentially suitable wetlands were identified and a field program was conducted to describe and compare these sites in terms of water and sediment chemistry, hydrology, and vegetation. The project was started too late to conduct a summer campaign; only autumn results were obtained. There were large differences between the wetlands in terms of metal loadings, groundwater inputs, water retention times, metal concentrations in wetland sediments, and vegetation communities. None of the sites, however, appeared to significantly reduce downstream loadings of metals or acidity levels during the fall. Prolonged drought at one site severely reduced flows and prevented the calculation of influent and effluent metal loadings. The apparent lack of biologically-related improvement of AMD was most likely a consequence of (1) low temperatures, ca. 4°C, (2) channelized flow patterns within the wetlands, and (3) limited contact of acidic drainage with anoxic sediments. Inputs from other seeps and groundwaters to the wetlands were significant complicating factors, especially at the Kam-Kotia site. High metal concentrations in wetland sediments indicated that the wetlands had removed metals in the recent past.

Project 3.12.2: Evaluation of Wetlands at Panel "A" Site

Expenditures: $45,000

This study was completed to establish if a beaver-constructed natural wetland at Elliot Lake provides significant treatment and control over water quality parameters associated with the oxidation of pyritic tailings and control of contaminant migration. A final report entitled: "Panel Wetlands: A Case History of Partially Submerged Pyritic Uranium Tailings Under Water" provides detailed information on surface and groundwater hydrology, chemistry, water balance and their seasonal variations, solid phase characteristics of sediment/substrate, bacterial enumeration and vegetation uptake of metals in the basin. The survey results have confirmed that the wetland/water cover system in the Panel wetlands basin is effectively controlling the acidic drainage from partially submerged pyritic uranium tailings. It is concluded that the system would continue to function as long as the water cover is maintained and its performance could be further improved if all the tailings were completely submerged (a small proportion remains uncovered). This study confirmed that shallow water covers in combination with a natural wetland have potential to permit "walk-away" with minimal maintenance at some tailings sites.

Project 3.13.1a: Passive Treatment of Small Seeps
Expenditures: ($90,000) - Associate Project

Passive treatment processes are being attempted and applied in Canada and the United States; and these include anoxic limestone trenches, lime organic beds, biotrenches, and biosorbents. Bench-scale treatment tests were carried out at Noranda Technology Centre in 1992 to evaluate 4 passive treatment methods. Process parameters such as pH, acidity, Eh, metal & sulphate concentrations, flow rates and hydraulic characteristics were determined. The results suggested that the best system for pH increase and metals removal can be obtained by using combinations of lime-organic mixtures and anoxic limestone trenches, and biosorbents and limestone systems. Although the completed work has shown some positive results, technical barriers would have to be overcome before applying the methods in the field at Canadian metal mines. Further work would be necessary in some areas, including an economic evaluation of methods, investigation of metal removing processes (including iron and aluminum) and the performance at low temperatures (0-4°C). For these reasons, the Treatment committee recommended not to proceed with a field test. However, these questions were difficult to address in further bench tests due to the time required to assess the effects and different and varying conditions encountered in the laboratory and the field. In the review of passive systems for treatment of AMD, (project 3.41.1) the questions of applicability of these systems in Canada is addressed.

Note: The final report was completed in early 1994 and was subject to an extensive review by the Treatment technical committee, and was found to be lacking in several aspects. The Treatment committee recommended, and the Management committee approved that this project be removed from the MEND program and be listed as a Associate MEND project. The final report is available from the MEND Secretariat as an Open File report.

Project 3.21.1a: Metals Recovery from Acid Mine Drainage - Phase A
Expenditures: $25,000

A background survey and a review of technology were completed on methods which could remove metals such as Cu, Ni, and Zn from acidic drainage and reduce the potential toxicity of treatment sludges. A summary report was completed in November 1991. Three technologies were determined to have economic and technical potential. They were; copper cementation, ion exchange, and selective precipitation. Since cementation is a well defined and frequently used method, ion exchange and selective precipitation of metals were the methods recommended for further research. These methods were assessed in projects initiated in 1992. It was indicated that a cross-Canada survey of acid drainage water quality was needed (project 3.22.1).

Project 3.21.2a: Removal of Metals from AMD - Chemical Treatment

Expenditures: $100,000

Several chemical methods were evaluated to selectively precipitate and recover metal ions from AMD. A conceptual flowsheet consisting of a three-step precipitation process was developed. The process consisted of oxidizing ferrous to ferric ion with H_2O_2 and precipitating ferric hydroxide sludge in the first step, recovering/recycling Zn and Cu as sulphide precipitates in the second step and, in the third step, removing residual metal ions remaining in the water via lime neutralization to obtain a final water quality in compliance with the regulated standards. Further bench scale investigations were carried out to optimize the initial flowsheet of separating iron as the hydroxide using lime and a dodecylamine surfactant, DDA, which could reduce coprecipitation of other metal ions. Copper and zinc were removed as the sulphide, and techniques were tried to produce a precipitate that could be recycled to a zinc production circuit (smelter - refinery).

The results show that more than 90% zinc recovery and greater that 50% Zn grade can be obtained with the three-step method. A preliminary economic analysis was conducted to compare the various options in terms of available reagents for precipitation and methods of oxidation. Based on the preliminary economic analysis, the feasibility of the proposed value recovery process would be dependent on the costs associated with chemical reagents and solid/liquid separation. The final report is in the editorial process and will be available in early 1995.

Project 3.22.1: Canada-wide Survey of Acid Mine Drainage Characteristics
Expenditures: $15,000

Fourteen companies participating in the MEND program were contacted to determine water quality at their currently acid generating sites. Data on the raw AMD streams at these sites were solicited using a written questionnaire. Detailed information on 72 untreated AMD streams from across Canada was compiled and is presented in the final report. The data were also assembled into a Lotus 1-2-3 spreadsheet designed to allow further analyses of the stream parameters based on selected criteria. The data on stream sources, flowrates, heavy metal concentrations, acidity, oxidizing conditions and suspended solids content have been extracted from the spreadsheet

and are presented in a concise tabular format to allow seasonal comparisons. Graphical concentration distributions are provided for several of these parameters.

Seasonal trends in flows and metal contents were observed for many of the stream characteristics. As expected, flowrates are almost always higher in the spring and fall compared to summer and winter. Few data were available on oxidizing conditions in AMD streams (e.g., Fe^{2+}/Fe^{3+} ratios, or redox potentials).

Project 3.31: Use of Lime Sludges for Capping
Expenditures: ($12,000 - Associate Project)

Inorganic materials when used for capping are susceptible to failure in providing water-tight and air-tight capping because of cracking as the rock or tailings pile settles, or because of desiccation. In this work, lime sludge was to be used as a filler in an inexpensive elastomeric material which in turn would be used as a capping cement. An elastomeric cement was to be designed which would contain a large proportion of sludge in its matrix. Investigation of the compatibility of the treatment plant sludge with elastomer would be undertaken and sludge modification undertaken if required. Samples of mine sludge were characterized with respect to its components and interaction with water. Some solid phases of the sludge were identified. A number of elastomeric compounds were tested as possible matrix material for sludge solids at various sludge loadings. It was determined that wet sludge solids (86% solids) could be blended with a number of elastomeric materials.

Unfortunately, the principal investigator at Laurentian University passed away and no report was submitted to MEND. The project was removed from full MEND status.

Project 3.32.1: Lime Treatment - Process Review and Sludge Stabilization
Expenditures: $60,000

Long term treatment of acid mine drainage is in essence the main component of the long term liability at many inactive mine sites. Contacts were initiated with suppliers, researchers, and the mining industry and an information base was developed regarding current and planned AMD chemical treatment practices. Chemical treatment of AMD, at almost all treatment facilities, is based on the use of lime neutralization and subsequent sludge precipitation. Cooperation received from industrial contacts was excellent. The information was reviewed, and standardized

summaries were prepared for selected documents. Considerable technical information was available on lime treatment but scientific evaluations of sludge characteristics and disposal were found to be limited.

The final step was a review and assessment of the current state-of-the-art of AMD treatment technology and sludge management practices to identify gaps. Considerable expertise and experience exists on the treatment of AMD with lime. Recommendations on research to fill the identified technology gaps were given. Further work on enhancing the stability of lime treatment sludges was indicated needed or recommended.

Project 4.1.1: Field Methods Manual - Tailings
Expenditures: $29,000

Accurate monitoring of a tailings impoundment requires that the samples collected for physical, chemical and microbiological analyses be of high quality. A manual of sampling methodologies applicable to tailings impoundments and involving the collection of representative solid, liquid and pore-gas samples was prepared. It offers guidance and recommendations on the selection of methods, emphasizing minimal sample disturbance and contamination. For each method, the objectives, descriptions, advantages and disadvantages are presented. Flowcharts are presented to summarize the methods and guide in their selection. A summary of quality control recommendations defined in the three primary chapters is also presented.

Project 4.2.1: Decommissioning Criteria
Expenditures: $15,000

The objective of the project was to review Canadian and United States legislation relevant to decommissioning acid mine drainage sites. The purpose of the review was to provide government agencies, industrial representatives and other organizations and individuals with an overview of the existing Canadian and United States regulatory framework relevant to decommissioning AMD sites and to summarize the criteria used by Canadian and United States regulatory agencies to assess the performance of a decommissioning AMD site. In general, regulatory strategies specific to decommissioning AMD sites are still in the development stage both in Canada and the United States. The criteria that would typically be used in assessing a site are effluent quality leaving the mine site and groundwater and surface water quality downgradient. Effluent limitations, drinking water standards and surface water quality criteria have all been developed at a federal level by the United States EPA. In Canada, non-enforceable water quality guidelines or objectives are prevalent, with enforceable site specific parameters incorporated into mine operation permits or licences. Apart from the federal guidelines, those of the provinces and territories in Canada were also covered, while for the United States, the review concentrated on the following seven states: Idaho, Nevada, California, Montana, Colorado, Pennsylvania and West Virginia.

Project 4.3.1: Standard Reference Materials - Tailings
Expenditures: $50,000

The key to reliable and reproducible analytical results is the availability of good, relevant standard reference materials. CANMET has an established Canadian Certified Reference Materials Program (CCRMP) through which four mill tailings materials were selected, prepared and certified. The four samples were prepared as composite reference materials from pyrite/pyrrhotite tailings from INCO, Falconbridge and Noranda. Analyses of nineteen major and minor elements were performed by seventeen laboratories on six replicates for each of the four standard materials. The reference materials, RTS-1, RTS-2, RTS-3, and RTS-4, are currently available through CANMET with all applicable supporting documentation.

Project 4.3.2: Reference Material NNP
Expenditures: $27,300

A standard material ensures the reliable comparison of results obtained internally and by different laboratories evaluating the acid generating potential of rock samples. No commercially available materials currently exist for this purpose. As a first step, approximately 300kg of processed standard material for ARD static testing was generated. Formal analysis of the material to obtain standard values for Net Neutralization Potential (NNP), total sulphur and sulphate were conducted in 1994 under the Prediction committee through an interlaboratory test program (1.16.2). Approximately 500 kg of non-ore grade biotite altered biotite feldspar porphyry material from the Noranda Bell Mine in British Columbia was processed to 80% minus 200 mesh by crushing, grinding and screening. The processed material was blended to ensure homogeneity, bottled under nitrogen in 3429, 100 units and the glass bottles sealed in foil pouches, again under nitrogen, to eliminate any further oxidation of the sulphides. Grab samples of the material were analyzed for total sulphur, sulphate, and neutralizing potential to obtain a preliminary value of the material's NNP. From preliminary results the material appears to be an acid consumer, containing 0.36% sulphur and having an NNP of approximately +40 kg $CaCO_3$/t. Characterization of magnesium and calcium carbonate as well as homogeneity testing (iron, sulphur) of the bottled material was completed. The material, NBM-1, is commercially available through the CCRMP and is also expected to be used to develop protocols for static prediction test through the MEND program (1.16.2).

Project 4.5.1b: Waste Rock Sampling Manual - Phase II
Expenditures: $55,000

A handbook was produced that provides a concise summary of currently available sampling techniques. The handbook is broken down into 3 main chapters each dealing with specific areas of waste rock sampling. Chapter 2 addresses representative sampling, sampling program design, data management and quality assurance and control. In Chapter 3, waste rock sampling is categorized and discussed in a common format which includes possible methods, objectives, background, rating, limitations and advantages, recommended procedures, requirements, cost, and references. The final chapter contains a summary of recommended techniques for obtaining information for rough cost estimates for decision making processes, predictive modelling of potential ARD and the identification of additional sample locations and sample types that may provide valuable secondary information for decision making. This handbook was produced following a detailed survey of waste rock sampling practices currently being applied at sites across North America, Australia and Europe. An experts' workshop was held in Toronto, March 11-12, 1994 following this review. The final handbook was a product of a comprehensive literature review, detailed industrial survey and the experts' workshop. This handbook is meant to be a guide only and users are cautioned that sampling strategies for waste rock piles will depend upon numerous factors that are site specific. Mathematical formulations applied to determine the number of samples required from a waste rock pile should be used with caution. Each distinct zone of a waste rock pile should be assessed separately and sample composites should be avoided. The handbook is currently being used as part of a Prediction project (1.41.1b)

Project 4.5.2: Field Sampling Quality Assurance/Quality Control (QA/QC)
Expenditures: $9,500

A literature review was completed on field sampling criteria with particular emphasis on quality assurance and quality control protocols. The focus was components of programs for predicting or detecting acid mine drainage and its environmental effects. Data quality objectives must be set which define the level of uncertainty that a decision maker is willing to accept. The report reviews the elements of field QA/QC programs for sampling surface and groundwater, effluents, sediments, soils, tailings and waste rock for chemical parameters related to AMD. It also reviews QA/QC programs for: stream flow measurements and biological effects monitoring, including sampling populations of fish, benthic invertebrates, periphyton,

zooplankton, and phytoplankton; metals in fish tissue; and the presence of *Thiobacillus ferrooxidans*. Although the elements of QA/QC programs for laboratory analyses are reasonably well defined with respect to the assessment of acid mine drainage was recommended that more emphasis be placed on the implementation of QA/QC protocols for field programs.

Project 4.5.3: B.C. Technical Guide Revision Monitoring Chapter
Expenditures: $53,700

The B.C. Draft Acid Rock Drainage Technical Guide was completed in 1989. Since that time various literature reviews and monitoring projects have been sponsored to address deficiencies identified in the guide monitoring chapter. A draft final report was submitted, reviewed in detail and revised. The report describes the principles, concepts and limitations of developing a monitoring program. A description of the ARD process, including the mine components involved, is given. Sampling techniques and parameters used to monitor ARD sources, pathways and impact are addressed. General guidelines for data management and the development of a working program are presented. The conceptual structure for developing an ARD monitoring manual was divided into 12 steps. Although the final report contains all essential information as detailed by the contract, it is not concise and has a distinct academic thrust. Thus, it is considered unacceptable by the Monitoring Committee.

Project 4.6.1: Assessment of Geophysical Monitoring Methods
Expenditures: $130,600

This investigation focused on electrical and electromagnetic geophysical applications since these methods have the potential to directly detect and map sulphides, areas of active chemical oxidation, and acidic seepage. The research was carried out at two sites in the Sudbury area. Due to the low background conductivities and the high conductivities of AMD, the electrical and electromagnetic geophysical methods were able to detect even small amounts of AMD in groundwater in first time surveys. The work carried out suggests that similar AMD plumes should be detectable at least near their source in most Canadian environments. The geophysical data were correlated with hydrological and chemical data from ongoing ground water investigations to establish the utility of the methods. The results confirmed that electromagnetic (EM) methods that remotely measure the conductivity of the subsurface are very useful for location and detailed three-dimensional mapping of AMD in groundwater. Airborne surveys can provide rapid reconnaissance scale surveys, while ground surveys and borehole surveys provide progressively more detail. In addition to the EM work, combined induced polarization (IP) and electrical conductivity surveys were tested on a large revegetated tailings area. The IP method detected disseminated sulphides as expected, and the combination of IP and conductivity surveys can beused for simultaneous three-dimenslonal mapping of sulphides and ground water quality in tailings. United selfpotential (SP) surveying showed strong SP anomalies over the tailings. A general recommended sequence for the use of electrical or EM methods in AMD site investigations is outlined in the report. Studies should be integrated using

geological, geotechnical, hydrological, geochemical and geophysical methods and data as appropriate. Data from the various disciplines should be entered and maintained in spatially linked databases.

Project 4.6.2: Continuous Monitoring of AMD - Literature Review
Expenditures: $50,000

This project aimed to identify and evaluate the capability of commercially available continuous monitoring technologies to address the monitoring requirements of AMD sites in Canada, and to identify the advantages and disadvantages of continuous vs. manual monitoring. An international survey of commercially available monitoring equipment (selective ions, redox potential, dissolved oxygen, pH, electrical conductance, etc.) applicable to AMD resulted in a list of just over 50 manufacturers. The identified equipment was divided into three categories: physical parameters (pH, dissolved oxygen, temperature etc.); chemical concentrations (Cu, Fe, As ions etc.); and meteorological conditions (precipitation, wind etc.). The evaluations and appended information focused on integrated commercially available continuous monitoring instruments. Five systems were identified which addressed the physical parameters while only two of these also monitored selected ion concentrations. One system, PIRANA, was recommended as most applicable. Actual expected detection limits, precision, maintenance requirements, cost and so on, were not addressed for AMD specifically and may be expected to vary considerably between sites. The concept of detailed data collection at an AMD site over a finite period to assess trends and potential correlations is considered worthwhile in the development of a focused, long term monitoring program. However, the specific application of the PIRANA system, as recommended in the report, is not being considered at this time.

Project 4.6.3: Review of State-of-the-Art Remote Monitoring Technology
Expenditures: $58,290

The study resulted in a summary of the state-of-the-art and a compendium of information on methods currently in use, organizations active in the field, suppliers of equipment and services, and lists of available products and equipment. Guides are presented in tabular form to address the applicability and effectiveness of various techniques to detect and monitor AMD. Each technique is also discussed separately. The handbook is the result of an in-depth literature search, an information survey of more than 900 organizations, the synthesis of catalogues from suppliers of equipment and services, and numerous discussions with scientists working in the field. The existing experience and information base should be expanded by the application of these technologies, to specific sites, by readers.

Project 4.6.4: Piezocone Field Test
Expenditures: $26,650

The project demonstrated that *in-situ* testing tools can typically be deployed at much lower costs than conventional investigation methodologies. An improved method for characterizing mine tailings resulted due to the coupling of the subsurface information that this technology provided with a lower cost and higher data repeatability as compared to traditional discrete sampling techniques. This study concentrated on INCO's Central Tailings Area in Copper Cliff, Ontario. During approximately 13 days of research on these tailings, a total of nearly 550 metres of RCPTU and CPTU soundings and 10 BAT water samples were achieved. A similar sampling program with traditional technologies would require approximately 50%-100% longer. An additional 65 metres of soundings were carried out at Falconbridge's Fault Lake tailings area. Although more detailed geochemical evaluations are recommended for comparison to traditional techniques, the results of this study suggest that RCPTU is an effective tool for comprehensive and economic characterization of sulphide-based tailings and surrounding native materials. The RCPTU provides full stratigraphic logging, a suite of geotechnical and hydrogeological parameters, and measurements of bulk resistivity which are indicative of the nature of dissolved constituents in the pore fluids. An overall evaluation of the RCPTU technology for any future geoenvironmental characterization work should be made in comparison to whatever technologies were in existing use on both a technical and economic basis. Further evaluation of this technique for specific site characterizations should also be made.

Project 4.7.1: Optimum Sampling Frequency
Expenditures: $27,000

The project objective was to determine optimum water quality sampling frequencies and most representative, measurable parameters (e.g. pH, conductivity) for AMD effluent by evaluating four of the most extensive water quality data sets associated with acid mine drainage in British Columbia. A number of potential failings were discussed, including: fixed-frequency single samples used in mean loading estimates; inaccurate or incomplete flow estimates; significant short-term events; and the overemphasis of analytical accuracy versus timely, representative sampling. It were recommended that acid mine drainage monitoring schedules be revised to consider the information needed for management; i.e., accuracy, lag times, risks, and parameter variation (spatial and temporal). As well, pre-operational studies at

proposed mine sites should include measures of natural variation and should span seasons of anticipated high acid mine drainage discharge to obtain adequate baseline data.

Project 4.7.2: Biological Monitoring of Acid Mine Drainage
Expenditures: $21,000

The objectives were to determine the most effective methods for biological monitoring of acid mine drainage through a review of existing methods and assess and recommend the most effective techniques. A variety of indicators are suitable for detecting impacts of AMD, but few have been linked to chronic whole organism responses. The most promising and proven biological monitoring techniques, however, include: benthic community responses; growth and reproductive parameters of fish populations; survival in a designated zone of impact; and other changes at the individual, biochemical level. It was determined that no single approach to the problem of biological effects monitoring will completely satisfy present needs. The most cost-effective approach to assessing ecosystem health in waters affected by AMD was found to involve a multi-disciplinary, "top-down" approach, which relies on the detection of impacts before they become irreversible.

Project 4.7.3: Aquatic Invertebrate Monitoring
Expenditures: $136,130

A three year mine research project was aimed at evaluating a trough apparatus for measuring the environmental effects of acid mine drainage on aquatic invertebrates. The study was carried out at Equity Silver in British Columbia to address allowable dilution rates of treated acid mine drainage that were discharged into Foxy Creek near the mine. In the first year a flow-through trough apparatus was constructed to test pre-selected concentrations of treated acid mine drainage. The apparatus accurately determined ecosystem response curves for effluent discharges as indicated in the available report titled "The Effect of treated AMD on Stream Macroinvertebrates and Periphytic Algae: An in situ Mesocosm Experiment". Ensuing work involved monitoring chemical and biological changes in a stream mesocosm that was dosed with a gradient of AMD from Equity Silver. Among other conclusions, the report indicated that the metal concentration in solution which causes a change in community structure may be lower when that metal is part of a complex solution of metals. Models of indices of benthic response to the gradient of AMD additions were generated and compared to the CCREM guidelines.

Project 4.7.4: Acid Mine Drainage Sediment Monitoring
Expenditures: $6,500

This project reviewed all available literature pertaining to sediment monitoring techniques and recommended the relevance and applicability of these techniques for measuring the impact of AMD. The review focused on assessment of sediment quality through sediment chemistry, bioassay testing and benthic macroinvertebrate community structure. Analytical methods for sediment chemistry are reviewed and summarized. Sampling devices, design, handling and preparation are evaluated with respect to sediment toxicity testing. Freshwater sediment bioassays with bacteria, algae, invertebrates and fish are reviewed. Guidelines for sediment chemistry, bioassay testing and benthic macroinvertebrate community assessment are provided, while stressing proper QA/QC. The application of the Sediment Quality Triad approach is recommended. This approach was developed to utilize three measures of sediment quality: sediment chemistry, which measures contamination; sediment bioassay, which measures toxicity; and biological community structures, which measures biological alteration.

Project 4.7.5: Ion Speciation
Expenditures: $35,092

The project objective was to provide estimates of the most probable species of a given metal, and their redistribution when raw AMD is mixed with receiving waters. Ionic speciation must be considered in the development of monitoring criteria and monitoring programs that attempt to predict the environmental impact of metals introduced into the environment. Toxicity of dissolved metals is dependant on the physical/chemical parameters associated with specific species. The model *B.C. Mine*, described in the report titled "Evaluation of *B.C. Mine* for Application to Acid Mine Drainage Regulations", gives projections of metal speciation at any one point in time from a given location. Historical data on the site combined with total metal levels provide the basis for potentially using predictive modelling as part of the regulatory process. With the information provided, in terms of organic binding and free metal ion activity, it may be possible to provide increased metal into the system before biological impact is observed. In addition to this, metal metabolism of indicator organisms as a controlling system may be an important consideration. Development of the model is not being pursued further at this time.

Project 4.7.6: Paleolimnology Techniques
Expenditures: $16,500

The extent of an operation's environmental impact can only be determined with respect to original, baseline values. Long term studies may be necessary to establish baseline levels at existing mine sites. However cost is often a prohibiting factor. The use of paleolimnology was therefore considered for describing past conditions including, for example, pre-mining conditions, at active or closed sites. Large scale studies in North America and Europe have successfully used paleolimnological indicators for effects of acid rain and these have been reviewed to evaluate whether similar techniques could be applied to AMD monitoring. The report, based on a literature review, concludes that it should be possible to develop a calibration data set which relates species assemblages of the chosen taxon to levels of AMD-related parameters. Currently there is no commitment to develop an appropriate calibration data set.

Project 4.8.1: Monitoring of the Flooded Solbec Pit
Expenditures: $136,500

The objective of the three-year monitoring project was to assess the long-term effects of relocating waste rock into an open pit and subsequently flooding the pit for the control of acid generation. The Solbec mine is located in the Eastern Townships in the province of Québec. Acid generation and drainage from waste rock on the surface resulted in the contamination of surface water and high concentrations of base metals. In 1988, 276,000 cubic meters of highly oxidized waste rock were placed in the dewatered pit, covered with a 5cm layer of limestone and reflooded to a water depth of 1.5m as part of a control measure. Characterization of the pit followed by a detailed monitoring program was undertaken to better understand the consequences of the chosen method of control on the surrounding environment. In the first year, the work included: mine site characterization; borehole placement (one upstream, two within the pit and two downstream); piezometer installation in the boreholes (the four latter, multilevel, the former, single level); and chemical analyses of solid and liquid samples from the pit and surrounding areas. The general hydrogeological regime for the site was prepared using all information available. Based on the first year it was recommended that additional boreholes be placed downstream of the pit. A review of a proposed geophysical survey indicated that the Solbec pit area would be a good site for EM surveys given th e resistivity of host rocks and the absence of both thick conductive overburden and interference from powerlines. Use of EM-31

and EM-34 coverage downstream and around the periphery of the pit was recommended.

Project 4.8.2: Sediment Sampling Probe Field Application
Expenditures: $51,080

AECL developed a method for locating and measuring groundwater discharges that are often obscured by the presence of overlying surface water. The technology allowed accurate and inexpensive environmental monitoring to be conducted at specific locations where environmental impact is occurring or is likely to occur. An electrical conductance, bottom-contacting probe was towed behind a slowly moving boat over more than 28 line kilometres of lake and river bottom. In the fall of 1992 and in June, 1993 electrical conductance surveys were done in two general areas: between the public access and the lake outlet of Kamiskotia Lake; and in the Little Kamiskotia river from the lake outlet to about 3km downstream. The Kamiskotia Lake is about 25km northwest of Timmins, Ontario. A laser positioning system was used on the lake but could not be used on the river due to the forested banks and adjacent swamps. As well, walking surveys allowed access in areas of water less than 03m deep. Shoreline surveys using a conductivity walking stick connected to a portable conductivity meter were performed along the eastern lake shore. The probe reconnaissance was used to target several areas of possible leachate discharge. These were studied quantitatively in order to evaluate the utility of the probe and to provide site-specific information. Discharges were confirmed by direct measurement of flux seepage meters or by measuring upward gradients, moderately high hydraulic conductivities or solute chemistry. Discharges ranged from 677 - 13,800us/cm and from pH 4.8 - 6.9. For a variety of reasons discussed, there is little correlation between pH and conductivity. Analyses of major ions, metals, and isotopes should be conducted to aid in distinguishing the underground sources. Adaptation of the probe to measure other specific contaminants should also be considered.

TECHNOLOGY TRANSFER

Project 5.1.1a-c: Provincial Workshops
Expenditures: $29,300

During 1993 three workshops were held by MENDO, NEDEM-Québec and the B.C. AMD Task Force. These technical sessions were well attended, demonstrating the strong continuing interest in the control of AMD by industry and government.

MEND Ontario (Sudbury, Ontario): 200 delegates; summary notes available.

NEDEM-Québœ (Val-d'Or, Québeœ): 120 delegates participated in the "Deuxième Colloque NEDEM-Québeœ"; proceedings available (en français).

B.C. AMD Task Force (Vancouver, British Columbia): Second annual British Columbia Acid Mine Drainage Symposium; abstracts of proceedings available.

Project 5.3.1,2: Laurentian Database
Expenditures: $35,000

A bilingual database has been established as part of Laurentian University's Mining Environment Database. There are over 10,000 abstracted references to journal articles, books, government reports, and conference proceedings.

The database includes a complete bibliographic description of titles as well as abstracts. In addition, actual documents are available from the Laurentian Library for consultation or for borrowing through interlibrary loan. Access to the Laurentian database is free to anyone with a telephone modem/computer hookup and by Internet (http://www.NRCan.gc.ca/mets/mend).

Project 5.4.1: Acid Rock Drainage Technical Guide - version française
Expenditures: $23,700

The Guide is a French version of the Draft Acid Rock Drainage Technical Guide. It provides the most comprehensive and easy-to-understand overview of the issue and technical aspects of acidic drainage (2.23.1). Increase in understanding of the issue, particularly in the mining industry, is a MEND priority. One hundred copies of the french version of Draft Acid Rock Drainage Guide were printed and seminars were held in Val-d'Or and Noranda to explain the guide.

Project 5.5.1: Preliminary MEND Research Plan
Expenditures: $25,000

The original research plan (RATS) was produced in 1988. This plan called for an expenditure of $12.5 million over 5 years. In May 1991, the MEND Management committee requested that each of the technical committees produce a revised plan for MEND. The technical committees reviewed the progress to date; examined the priorities; produced a focused plan with distinct outputs; and defined an end to the program. The Revised Research Plan for MEND includes the decisions of the MEND Board of Directors to expand the program to $18 million total expenditure and to extend the program to the end of December 1997.

Project 5.6.1: Second International Conference on the Abatement of Acidic Drainage
Expenditures: $127,000

The Conference was an outstanding success. Over 500 delegates from around the world attended the 3 day conference at the Sheraton Hotel in Montréal on September 16, 17 and 18, 1991. There were 134 technical papers presented in 15 different sessions. Also there were 3 days of poster sessions. Workshops were presented on September 14 and 15 and these workshops were well attended. There were field trips after the conference to; Bathurst, New Brunswick; Noranda, Québœ; and to Elliot Lake, Ontario. MEND participants took the opportunity to present and listen to many of the excellent presentations, to meet many people from Canada and around the world, to have several MEND technical committee meetings and to invite interested guests to these meetings. Many attenders commented that the conference was the best conference of any kind that they had attended. The proceedings (4 volumes) are available from the MEND Secretariat.

Project 5.6.2: Third International Conference on the Abatement of Acidic Drainage
Expenditures: $12,000

To promote communication in the areas of acidic drainage and land reclamation, two major conferences were combined into a joint conference that was held in Pittsburgh in April 1994. Over 1,200 people attended this conference, out of which about half were concerned with Acidic Drainage. Eighty-five refereed papers, 75 posters and 5 training courses were presented on acidic drainage issues. MEND participants and contractors contributed 43 papers and posters. There was a special panel discussion

on international acid drainage research chaired by MEND. As a cosponsor, MEND participated in planning sessions, reviewing papers, chairing sessions and presenting papers. This conference was an excellent opportunity for MEND members to exchange new information with others working in the field of acidic drainage. No new breakthroughs were presented at the conference that suggest alteration of the MEND program of research and development. At the same time, old misconceptions such as the idea that passive systems are widely applicable continue to be promoted.

Project 5.8.1: Economic Evaluation of MEND-developed Technology
Expenditures: $40,000

This study was carried out based on actual mine closure projects selected with a reference to the study objectives. Generic tailings/waste rock disposal sites were also considered to address specific cost issues such as the availability of borrow materials or the area-volume ratio in the case of a waste rock dump. The following representative unit cost ranges (Net Present Value) were derived for the two basic AMD technologies (1994$/ha of tailings "footprint" or 1994$/tonne of waste rock):

	Tailings	Waste Rock
Collect and Treat	180,000 - 280,000	0.4 - 2.0
Dry Covers	100,000 - 300,000	1.0 - 1.5

In general, the composite soil cover and plastic liner technologies were confirmed to be the most expensive. From the cost perspective, it seems unlikely that these technologies would be considered preferable for many mine sites. The study results also indicate that it is unlikely that a walk-away option would be selected for a major waste rock dump that generates net acidity at the time of closure. The study indicated that the self-sustained water cover and the collect-and-treat technologies may represent the best options from the perspective of the implementation costs. Hence, with regard to future AMD research directions, an emphasis should be made on these two technologies.

Number	Title
1.15.2	AMD from Open Pits - Expansion and Verification of MINEWALL 2.0
1.16.4	Evaluation of Static and Kinetic Prediction Test Data and Comparison with Field Monitoring Data for Selected Mine Sites
1.19.2	Scaling Analysis of Acid Rock Drainage
1.41.3a	Waste Rock Pile Monitoring Ontario - Phase I
1.42.1	Critical Review of Geochemical Modelling
2.11.4A	Evaluation of Underwater Disposal
2.17.1	A Review of the Use of an Elevated Water Table as a Method to Control and Reduce Acidic Drainage in Tailings
2.22.2a	Evaluation of Dry Covers Built from Mine Tailings
2.31.1b	Dry Covers on Waste Rock - Heath Steele
2.35.2	Lysimeter Evaluations of Cover Alternatives - Noranda
2.36.1	In-Pit Disposal - Case Studies
2.42.1a	Development of Synthetic Polymers - Laurentian
3.14.1	Evaluation of Passive Systems for the Treatment of AMD
3.21.1b	Removal of Metals from AMD - Ion Exchange
4.6.5a	Demonstration of a Field Method to Determine the Oxygen Flux Across the Surface of Tailings
5.1.2(a)	Workshops
5.2.1a-d	Communications Plan - CIMM Lectures, Brochure, Video

Associate Projects

- Hydrogeology at Waste Rock Dumps
- Study of Submarine (Ocean) Tailings Disposal
- Evaluation of the Effectiveness of Reclamation Measures at Mount Washington
- Segregation of Waste Rock Rock at the Samatosum Mine

PREDICTION ***Modelling***

Project 1.15.2: AMD from Open Pits - Expansion and Verification of MINEWALL 2.0

Budget: $88,000

Sponsors:

CANMET	$25,710
British Columbia	$25,710
BHP Minerals	$14,600
Noranda	$20,060

Expenditures: $86,080

Contractor: Morwijk Enterprises Ltd.

Objectives:

This project addresses three objectives: expansion, improvement, and verification of the original MINEWALL computer code with appropriate user instructions; the collection of field data at two representative minesites; and the subsequent calibration of MINEWALL Version 2.0 using this field data.

Outputs:

In 1990, a literature review on the physical and geochemical impacts of mines, a short term field investigation at Equity Silver, B.C., and the preliminary development of the computer program MINEWALL to simulate effluent quality from open pits were completed (1.15.1). The literature review was to the end of 1993. The known limitations of the model code such as the arbitrary equations describing pit flooding and decreasing sulphide oxidation through time, and the inability to explicitly simulate effluent quality from underground mine walls were also addressed. Version 2.0 of the model was written as several individual, updatable modules. Field data was collected at the Island Copper and Bell Mine open pits in British Columbia.

The complexity of the model resulted in enormous amounts of computer code that cannot be handled by the current DOS-based programming language. After consultation with the Prediction committee, the contractor simplified the computer code to retain user-friendliness without simulation of complex scenarios. MINEWALL predictions were verified by mathematically comparing predictions against known outcomes using simplified data sets followed by complex data sets and finally by real data sets.

The project was completed in September 1995. Three separate reports, the literature review and conceptual model's, application to three mine sites and a user's manual

will be available in May 1996. Extension of the model to open pits containing waste material is currently under development (1.15.3).

PREDICTION ***Chemical Prediction***

Project 1.16.4: Evaluation of Static and Kinetic Prediction Test Data and Comparison with Field Monitoring Data for Selected Mine Sites

Budget: $27,200

Sponsors: Gibraltar Mines Ltd. $6,800

Placer Dome Canada Ltd. $4,000
Cominco Ltd. $3,400
Teck Corporation $7,000

Expenditures: $21,200

Contractor: University of British Columbia

Objectives:

This project was part of an M.Sc. thesis whose objectives included:

- determining the ability of static and kinetic prediction techniques to identify on-site conditions;
- investigating the relationship between static prediction parameters and lithogeochemistry;
- identifying the processes and reactions that affect both laboratory and field kinetic tests and comparing laboratory and field determined rates of metal release and water quality trends;
- investigating the relation between static prediction parameters and kinetic (field and laboratory) information; and
- providing a review of the current interpretative and reporting methodology used to assess ARD prediction data.

Outputs:

The Database for Acid Rock Drainage (DBARD) and a detailed study of the tailings impoundment at Gibraltar-McLeese Operations, B.C. provided the basis for this study. Identification of 'indicator' elements can be used to calculate acid generating and neutralization potentials from site specific correlations and be included in kinetic tests and on-site monitoring programs to characterize oxidation and dissolution reactions. The water quality and oxidation/neutralization rates for the DBARD kinetic tests are not predicted by the static test data due to the short time frame of the tests, the time lag to ARD and/or the inaccurate values of the static test data. Kinetic tests need to be initiated as early as possible to allow stable conditions to be established and the maximum amount of time for leaching. With longer term kinetic tests, the assumption used in calculating oxidation/neutralization rates can be extrapolated into the future needs to be verified through additional test work. Interpretation of the Gibraltar static prediction data for the tailings inferred a potential for ARD after approximately 3 years of kinetic testwork although the pH is

neutral. Oxidation and neutralization test reactions are also occurring on-site, although water quality is predominantly affected by the chemistry and infiltration/migration of the tailings pond supernatant. Recommendations for analyses, data manipulation, criteria for interpretation, and reporting of ARD prediction data have been made for the different stages of waste characterization: 1) mineralogical characterization, 2) static testing, and 3) kinetic testing.

PREDICTION ***Chemical Prediction***

Project 1.19.2: Scaling Analysis of Acid Rock Drainage
Budget: $21,000
Sponsor: Environment Canada
$15,000
Expenditures: $15,000
Contractor: Synergetic Technology

Objective:
The main objective of this project was to determine the simple scaling laws that govern the geochemical and thermodynamic behaviour of pyritic rock in waste rock piles. The current approach in setting up tests for the evaluation of ARD material was assessed and an evaluation of the validity of current practices in scaling between bench, pilot and field scale for spatial, temporal, physical, chemical and biological processes involved in acid generation was successfully completed.

Outputs:
The scaling parameter, δ, was an innovative feature of this project. This project was part of an effort to design practical indicators that would combine quantitative laboratory data with large-scale effects observed in waste rock piles. The dimensionless scaling parameter, δ, combines information about pile porosity, pile size, effective reactive surface area, temperature dependence of the rate of pyrite oxidation, oxygen diffusion in the gas phase, heat of the pyrite oxidation reaction, thermal conductivity of waste rock, and ambient temperature. This sensitivity analysis provided information about the required accuracy of experimental tests and the relative importance of parameters governing different physical and geochemical processes responsible for ARD. Critical values of the scaling parameter δ, at which bifurcations or *thermodynamic catastrophes* leading to accelerated acid generation rates, have been determined for different scenarios. The critical dependence of ARD on pile porosity, pile size and reactive surface area is one of the conclusions of the bifurcation analysis.

The results of the scaling analysis offer the possibility of a cheap and fast preliminary assessment of the expected environmental impact as the model produces realistic results for acid generation rates.

A project to provide *thermokinetic* tests in order to provide experimental information necessary for a predictive waste rock model are under development (1.19.3).

PREDICTION ***Waste Rock Basic Knowledge***

Project 1.41.3a: Waste Rock Pile Monitoring Ontario - Phase I
Budget: $30,000
Sponsors: ..... CANMET
$15,000
Ontario $15,000
Expenditures: $21,740
Contractor: Trow Consulting Engineers Ltd.

Objective:
The objective of this project was to develop a workplan to provide detailed laboratory and field programs, data analyses, data interpretation and exact costs, for an extensive 2-year monitoring program for the waste rock pile at INCO's Whistle Mine in Sudbury.

Output:
A detailed workplan for the implementation of a 2-year monitoring program for a waste rock pile was prepared. This plan served as the basis to prepare the scope of work for the request for proposal to monitor the Whistle waste rock. Future plans also include developing guidelines for monitoring/characterization programs for other waste rock piles that may require monitoring in the future.

PREDICTION ***Waste Rock Modelling***

Project 1.42.1:	Critical Review of Geochemical Modelling
Budget:	$60,000
Sponsors:	CANMET
	$30,000
	Ontario $30,000
	Teck $4,000
Expenditures:	$64,000
Contractors:	Noranda Technology Centre
	Alberta Research Council
	University of Western Ontario

Objective:
The two objectives of the work were: to identify the various geochemical processes occurring in waste rock piles at all stages of acid generation, and to list and thoroughly review existing geochemical models which are being used, or can be adapted, for predicting metal species and their concentrations in waste rock piles.

Outputs:
The geochemical processes which most control ARD quality are precipitation and dissolution, chemical diffusion, and surface reactions. Precipitation and dissolution control neutralization of acidic solutions and fixation of metals within solids. Chemical diffusion and surface reactions control the rates at which all precipitation and dissolution reactions occur. Quantitative reaction rates are required to accurately predict water quality from waste rock piles. Reaction rate equations need to incorporate the important influence of rate-modifying mechanisms such as bacterial catalysis. Drying and wetting are the most important physical processes that affect water chemistry, by concentrating aqueous solutions to the point of precipitating solids and subsequently dissolving and removing these solids from solution contact. Field data required to describe geochemical processes in waste rock include detailed water analyses, rock mineralogy and trace element chemistry, exposed surface area, temperature, oxygen availability and water infiltration rates. Thermodynamic and reaction rate data for important secondary minerals in ARD are insufficient. Existing geochemical models are divided into five classes: equilibrium thermodynamic models, mass transfer models, coupled mass transport-mass transfer models, supporting models, and empirical and engineering models. Each class of geochemical models can be viewed as addressing a different type of ARD prediction objective.

A report describing the work was released in April 1995. The report also served as a platform for a workshop on mathematical prediction held at Noranda Technology Centre December 8, 1995.

PREVENTION AND CONTROL ***Underwater Disposal***

Project 2.11.4a: Evaluation of Underwater Disposal Site - Buttle Lake
Budget: $250,000
Sponsors: Placer Dome ..... $ 94,000
CANMET $150,000
Environment Canada ..... $ 6,000
Expenditures: $250,000
Contractors: Rescan Environmental/ASL Laboratories
University of British Columbia/Environment Canada (NWRI)

Objective:
The objectives of the Buttle Lake program were to address the recommendations made in the first peer review (2.11.1d) and to provide the additional information needed to support the application of the subaqueous disposal method. The focus of the project was on field and analytical techniques to improve the measurement of metal fluxes at the sediment/water interface.

Outputs:
Buttle Lake, located in Strathcona Park on Vancouver Island, presented an opportunity to study the reactivity of mill tailings disposal into a deep lake. The tailings are covered by a veneer of almost one decade's accumulation of natural sediment. Of particular interest was the reactivity of the tailings that had admixed with natural, surficial sediments as they had been exposed to oxygenated bottom-water since the time of original deposition in the South Basin of the lake (1966-1984).

In keeping with the recommendations of the peer review (2.11.1d), a work plan that addressed the key issues of QA/QC and salient aspects of sediment chemical-seasonality was developed and implemented. The work addressed tailings reactivity by high-resolution observations of trace-metals contents and other sensitive "tell-tale" indicators within the interstitial waters of the sediments and across the sediment-water interface. The dissolved metal concentrations within Buttle Lake are among the lowest observed in the last 20 years of observations despite continued inputs of several trace metals (most notably Zn) from acidic drainage in the Myra Creek watershed. Simple flux-based diffusion calculations suggested that effluxes of Cu, Pb, and Zn to the South Basin bottom waters are small and have limited impact on water quality; very little, if any, oxidation of sulphide particles can be accommodated by the near-surface pore water data. These observations are consistent with those of previous studies of Buttle and other lakes.

Recommendation:

No further work is planned at Buttle Lake. The results have been assessed during the second peer review (2.11.1e).

PREVENTION AND CONTROL ***Wet Barriers***

Project 2.17.1: A Review of the Use of an Elevated Water Table as a Method to Control and Reduce Acidic Drainage in Tailings

Budget: $50,000

Sponsors: ..... Ontario $25,000

CANMET $25,000

Expenditures: $50,000

Contractor: SENES Consultants Limited

Objective:

The objective of this project was to evaluate, technically and economically, the use of an elevated water table in sulphide-containing tailings to control and reduce acidic drainage.

Outputs:

An Elevated water table may be very useful in developing passive decommissioning strategies for reactive tailings, or at least mitigating acidic drainage treatment requirements by reducing the quantity of sulphide mineralization available for oxidation. The concept has been studied at only a few tailings management areas, and was proposed for use at a few other sites.

This study focused on the use of an elevated water table and was meant to serve as a useful reference document. It describes relevant theories, elevated water table concepts, and summarizes the limited empirical and scientific data currently available. In concept, elevated water tables are ideally suited for application in Canada due in large extent to typical net precipitation conditions. Not all tailings basins are suitable for elevated water table application and site-specific conditions will dictate the suitability of the concept. Even where elevated water tables may not totally prevent acid generation, their use could substantially reduce long term treatment liabilities. The concept is also attractive as it addresses many of the key concerns associated with the use of moisture retaining dry covers and wet covers. The use of groundwater flow barriers within tailings is attractive but technical and field studies are required to further develop this concept and explore more cost-effective methods of creating barriers. A potential deficiency is a lack of scientific data (case histories) related to long term monitoring and fluctuation of water tables and moisture content in tailings. The final report will be available in 1996.

Recommendation:

The report shows that the elevated water table concept has long term merits for the control of acidic drainage. A cost evaluation indicated the potential benefits of the

elevated water table concept. Although MEND plans no further work, the concept could be further evaluated in large scale field tests by industry.

PREVENTION AND CONTROL ***Dry Barriers***

Project 2.22.2a: Evaluation of Dry Covers Built from Mine Tailings
Budget: $234,880
Sponsors: .....Québec
$133,000
Itec Minéral inc. ..... $ 20,000
Lac Minerals ..... $ 10,000
CANMET $107,000
Expenditures: $270,000
Contractor: École Polytechnique

Objective:
The study evaluated, under controlled laboratory conditions, the effectiveness of using fine tailings as a lower cost alternative for the capillary material in layered cover systems to control AMD.

Outputs:
Dry barriers are usually constructed from naturally-occurring geological materials maintained at a high degree of saturation. Low permeability soils may not be economically available, therefore alternate materials (e.g. fine tailings) having similar physical properties may be substituted.

More than 30 tailings sites were sampled and analysed as possible cover materials and a literature review was completed. Preliminary tests, including mineralogical analyses, re-grain size determination and Atterberg limits, allowed for the selection of five sites where the tailings were sampled for more detailed studies. The laboratory program included the evaluation of material properties (compaction, consolidation, hydraulic conductivity, moisture retention curves, diffusion coefficient of oxygen), together with physical and numerical modelling of cover systems.

The results confirmed that sulphide-free fine tailings offer some promising characteristics as cover materials. For example, if high saturation ($\geq$ 90%) can be maintained in the cover through capillary barrier effects, then a layer of fine material (i.e. tailings) sandwiched between two sand layers will effectively reduce the oxygen flux to the reactive tailings material by a factor of 1000 or more. Recent work described in the literature shows that silty soils, with physical properties similar to some of the tested, tailings can be used with success to limit AMD.

Recommendation:
The results are very encouraging, and it was recommended that the research program be continued. The committee recommended that a laboratory study (2.22.2b) to

optimize the efficiency of cover designs to further analyse the practical use of non-reactive tailings in layered cover systems be completed. A field program is also planned (associate project).

PREVENTION AND CONTROL ***Waste Rock***

Project 2.31.1b: Dry Covers on Waste Rock - Heath Steele
Budget: $367,700
Sponsors: Noranda - BM&S (Heath Steele) $121,300
CANMET $154,500
New Brunswick..... $ 91,900
Expenditures: $367,700
Contractors: ADI Nolan Davis/Heath Steele Mines

Objectives:
The project objectives were to evaluate the performance of a soil cover over an existing acid-generating waste rock pile and to assess the cover's effectiveness as a method for the long term management of acid generating waste rock.

Outputs:
Construction of the multi-layers engineered cover was completed in September 1991. By using a broad set of monitoring instrumentation installed in the pile and cover during construction, the performance of the pile was continuously monitored. Oxygen and temperature were monitored monthly and after placement of the cover, infiltration rates, leachate quality and the moisture content of the various soil layers of the cover were also measured.

The results clearly indicated reductions in the gaseous oxygen concentrations in the pile. Initial concentrations of 20%, prior to cover placement, were reduced to about 1%. Pile temperatures decreased following installation of the cover, but later appeared to be controlled primarily by climatic conditions, rather than sulphide oxidation rates. The glacial till layer within the cover maintained its moisture content at the level it was placed.

Of critical importance for evaluating the effectiveness of the engineered soil cover, is the results of the water chemistry from seepages emanating from the pile. The unique design of the cover allows a full water balance to be calculated. This has shown an infiltration rate of about 2% of precipitation. However, the water quality of the effluent did not significantly changed. Some improvement in water quality was obtained after 1994. This will be further studied by continued monitoring. Although the concentrations and loadings were greatly reduced, they still exceeded the regulations, thus dictating treatment of the drainage before discharge.

Recommendation:

Despite the promising performance to date, additional monitoring (2.31.1c) is required before its long term stability can be properly assessed as a full scale final closure measure.

PREVENTION AND CONTROL ***Waste Rock***

Project 2.35.2: Lysimeter Evaluations of Cover Alternatives - Noranda
Budget: $275,000
Sponsors: .....Noranda
$ 152,000
Québec ..... $ 84,000
CANMET ..... $ 43,000
Expenditures: $279,000
Contractors: Noranda Technology Centre/McGill University

Objective:
The objective was to evaluate the relative effectiveness of various techniques for controlling acidic drainage in waste rock.

Outputs:
The investigation involved outdoor lysimeter tests and laboratory column experiments. Cover techniques investigated were a 1m water cover, a soil cover consisting of a 150mm water-saturated clay layer sandwiched between two 75mm thick sand layers, and a 150mm wood bark layer. Limestone and phosphate were added at 1% and 3% dosages. Control experiments were also carried out for comparison; they started producing acid after 5 weeks.

Monitoring of the effluent water quality was carried out for 154 weeks. Water cover was the most effective control technique of indoor testing, followed by 3% and 1% limestone, soil cover and, finally 1% phosphate. The effectiveness observed outdoors were: water cover, 1% limestone, soil cover, and 1% phosphate. The effectiveness of limestone and phosphate increased with increasing amounts. All the techniques, with the exception of the water cover, were found to be slightly more effective in the laboratory than outside. The wood bark accelerated acid production by about 60% in the laboratory and 500% outside. The role of the iron oxidizing bacteria (*Thiobacillus ferrooxidans*) was invoked to explain this acceleration. This was confirmed when a bactericide, added to the wood bark cover, reduced acid generation considerably. Thus, a wood bark cover is not considered a good technique for reducing acid generation in sulphide-bearing waste rock.

The water covered waste began to release low concentrations of metals (zinc, iron and lead) after two and a half years of study. The delay in metal release may be attributed to the presence of trace amounts of alkaline minerals which were probably depleted after two and a half years. The results of the study indicated that, although a water cover may not completely prevent oxidation, it will reduce acid generation considerably. In fact, when considering both feasibility and efficiency, it is the most promising ARD technology known to the industry.

Recommendation:
No further work is planned. The work in this research area is being continued under the Stratmat project (2.36.2).

PREVENTION AND CONTROL ***Waste Rock***

Project 2.36.1: In-Pit Disposal - Case Studies
Budget: $50,000
Sponsors: ..... HBM&S $10,000
Ontario $20,000
CANMET $20,000
Expenditures: $50,000
Contractor: SENES Consultants Ltd.

Objective:
A major deficiency that previously existed was a central file of data relating to the use of mined-out pits for mine waste disposal. The objective of this study was to thoroughly review the published literature and to make contact with national and international private and public sector groups to complete this review. With the data in hand, both industry and governments will be in a better position to comment upon the advantages and issues related to pit disposal.

Outputs:
Open pit mines that have ceased production are increasingly being considered for the permanent and environmentally acceptable disposal of mine waste rock and tailings that are, or have the demonstrated potential to become, sources of acidic drainage. The report addresses key aspects that need to be taken into consideration when evaluating the in-pit disposal of waste and presents 12 case studies.

There are four basic concepts for the placement of wastes in pits: underwater disposal; elevated water table; dry disposal; and perched water table. They are described in terms of theoretical concepts and practical aspects: examples of research and field applications are provided from the published literature. The success of an application would depend on many technical factors as well as mine related constraints. The potential costs for future in-pit disposal of wastes should be considered in the economic evaluations used to establish final pit limits.

The practice of in-pit disposal is more widespread than originally thought. Detailed information on many of the identified sites does not exist. Twelve case studies were selected and are presented in detail in the report: seven case studies describe in-pit disposal programs that have been implemented (Solbec, Owl Creek, Rabbit Lake, Udden, Collins Bay "B" Zone, Stratabound, Cluff Lake "D" Zone); two case studies describe proposed in-pit programs (Island Copper and Deilmann); and three case studies provide technical information from other pits which will likely be of interest to persons evaluating in-pit disposal programs (Robinson Mining, Gunnar and Berkeley).

Recommendation:

The final report recommends that a field study be completed. The Owl Creek pit located near Timmins was suggested as a possible site. The committee decided that a field study would be too site specific yielding few new insights and thus no further work is planned by MEND.

PREVENTION AND CONTROL ***Others***

Project 2.42.1a: Development of Synthetic Polymers - Laurentian
Budget: ($45,000)
Sponsors: ..... INCO ($22,500)
Ontario ..... ($22,500)
Expenditures: ($30,000)
Contractor: Laurentian University

Objective:
The project objective was to synthesize a polymeric material(s) with specific engineering characteristics. The ideal material(s) was to have the following properties, in tailings ponds, it would: a) be water soluble; b) provide long term bactericidal action; c) strongly adsorb onto particulate matter; d) flocculate fines when wet; e) act as a binding agent for fines when dry; and f) complex any previously leached metals. In waste rock it would also: g) be readily foamed to allow penetration into the pile; and h) have virtually no oxygen permeability.

Outputs:
A number of approaches were tried in synthesizing various components of the required polymer(s). As anticipated, most were not effective and efforts were focused on those showing significant results.

Due to the death of the principal researcher the work was not completed. Two reports, entitled "The Synthesis of a Water Soluble Chelating Polymer Containing Vicinal Oxime Groups" and "The Synthesis and Chelating Ability of Water-Soluble Polymers" were prepared by graduate students at Laurentian University.

Recommendation:
Both reports were subject to review, and were found to be of no use to the program because they failed to meet the objectives of the study. The Prevention and Control committee recommended, and the Management committee approved, that this project be removed from the MEND program. Copies of the two reports are available from the MEND Secretariat and Laurentian University.

TREATMENT

Project 3.14.1: Evaluation of Passive Systems for Treatment of AMD
Budget: $60,000
Sponsor: ..... CANMET
$60,000
Expenditures: $70,000
Contractor: Kilborn Inc.

Objectives:
The objective of this project were to complete a review and evaluation of passive treatment systems; to identify the critical design criteria and operating parameters; provide estimates of costs for treatment of AMD using passive systems; and to make recommendations on their applicability in Canada.

Outputs:
The contractor reviewed and summarized the available information on passive treatment systems, particularly those methods using biotechnology. Considerable research and process development has been done on passive systems for treatment of AMD, particularly in the United States. In Canada, through the MEND program, significant resources have been allocated to projects related to passive treatment options.

The performance and the applicability of these systems was reviewed and several process-limiting factors, such as temperature, flow rates, and rates of addition of bacteria nutrients, were identified. The 1995 draft report identified further needs and information that were becoming available to extend the application of passive systems at metal mine sites in Canada. An important objective of this study was the identification of conditions of application and recommendations on the applicability of passive treatment systems in Canada. An analysis of capital and operating costs required for the passive treatment of AMD is still to be completed. The contract was extended to include this new information and a final report was received. Passive treatment of AMD will be the subject of a short course at the Vancouver conference in 1997.

In summary, where metal and acidity levels are elevated, which is the case at most metal mine sites, passive methods have limited application. Also, cold conditions and spring freshettes are major impediments to the application of these systems. The use of a flooded pit to treat acidic drainage using an anoxic organic-sulphate reduction system has some potential if the water acidity is low and water temperatures are above 8-10°C. Such a system is being installed at a closed-out copper mine on Vancouver Island.

TREATMENT

Project 3.21.1b: Removal of Metals from AMD - Ion Exchange
Budget: $64,000
Sponsors: ..... Teck $10,000
Falconbridge ..... $ 4,000
Ontario $30,000
Homestake $20,000
Expenditures: $64,000
Contractor: CANMET

Objective:
Assess and demonstrate the applicability of ion exchange to remove selected metals from acidic drainage.

Outputs:
The extraction of metals from acid mine drainage solutions using selected ion exchangers was studied in batch and column tests using synthetic solutions. The tests were carried out at low, at mildly acidic, and at neutral pH. The ion exchange extraction of metals from acid mine drainage was shown to be possible, but the extraction efficiency varied widely. Copper and antimony can be extracted with relatively good selectivity, even at low pH. Copper presents good prospects for recovery, but more tests would be needed to address the problems associated with slow adsorption kinetics and co-extraction of iron. The extraction of Cd, Ni and Zn is feasible under mildly acidic or neutral pH with moderate efficiency.

The bulk extraction of Cd, Ni and Zn at neutral pH is feasible with either a chelating resin or a synthetic zeolite. Preliminary calculations indicate that the ion exchange alternative may be economically advantageous, especially if zeolites are used. Ion exchange resins show potential for lowering the metal content of treatment sludges produced downstream. This could provide a low maintenance scenario at a site where acidic drainage has ceased, and the lime treatment plant is shut off.

Additional experiments were conducted on an actual acid mine drainage solution. Results indicate that the extraction of copper, antimony and zinc was technically feasible from the solution. The recovery of zinc requires a partial neutralization to pH 4.5 to eliminate ferric iron from the solution. Further neutralization to pH 10, as is common practice in the field, may be not necessary after ion exchange. This may represent a significant reduction in lime consumption and in the toxicity of the neutralization sludge.

A brief review was undertaken to address the economical and ecological aspects of the lime neutralization, with and without ion exchange; the results were dependent on metal values and volumes of AMD to be treated.

MONITORING

Project 4.6.5a: Demonstration of a Field Method to Determine the Oxygen Flux Across the Surface of Tailings

Budget: $11,100

Sponsors: ..... INCO $11,100

Expenditures: $9,793

Contractor: University of Waterloo

Objective:

The objective of this project was to demonstrate the utility of a new oxygen flux measurement technique to determine the rate of oxygen uptake across the surface of mine tailings.

Outputs:

An innovative method of measuring oxidation rates based on oxygen consumption at the tailings surface was applied to selected areas at INCO's Copper Cliff tailings in order to demonstrate the methodology and to provide additional monitoring data for the Low Sulphur tailings test-plot program being conducted by INCO. The methodology involves measurement of the rate of oxygen consumed at the tailings surface. Results are reported as the flux of oxygen across the tailings surface. The lower detection limit with current methods is about 0.5 to 0.1 mol-O_2 $m^{-2}a^{-1}$. Three areas of the Copper Cliff tailings were selected for this study. The Low Sulphur tailings test plots were instrumented with three sampling tubes in each of the three test plots. Eight sites were instrumented at the Whissel Dam to assess the rate of oxygen uptake through the clay cover placed on the tailings dam. One additional site containing a high concentration of fresh pyrrhotite tailings was also instrumented for comparison.

The measured oxygen flux values over a four day period ranged from about 8 to over 1000 mol-O_2 $m^{-2}a^{-1}$ for the 22 measurements made. The highest value of oxygen flux was observed in the high pyrrhotite tailings. The lowest value measured was located at one of the clay-covered sites at the Whissel Dam. Values were compared to oxygen flux values estimated by INCO based on oxygen profiles and tailings moisture content (oxygen gradient method). The oxygen gradient method generally provides higher oxygen flux estimates than the oxygen consumption method as shown in this and other studies. One recommendation from this study is for further study of measurements on vegetated clay covers to differentiate between tailings oxidation below and oxygen consumption in the active soil zone of the cover.

TECHNOLOGY TRANSFER

Project 5.1.2(a): Workshops
Budget: $30,000
Sponsors: New Ideas Fund Contributors
$30,000
Contractor: Ken Wheeland

Objectives:
To present workshops on completed topics of the MEND program across Canada.

Rationale and Fit With Program:
During 1994, and early in 1995 workshops were presented to technical audiences across Canada. These workshops were well received and both the contractors who were representing their work and the participants found the workshops useful. Also useful feed feedback was received that helped to focus future and final work in the MEND program.

The following topics were presented at various locations:

Topic	Presenter(s)	Location, Date
Chemical Treatment	SENES	Val d'Or, Nov. 1994
Chemical Treatment	SENES	Vancouver, Feb. 1995
Cost Evaluation of AMD Technologies	Geocon	Vancouver, Feb. 1995
Cost Evaluation of AMD Technologies	Geocon	Sudbury, May 1995
Coal- Acid Mine Drainage	Various	Cape Breton, June 1995
Chemical Treatment	SENES	Sudbury, Oct. 1995
In-pit Disposal	SENES	Sudbury, Oct. 1995
Chemical Modelling	Various	Montreal, Nov. 1995

Workshops to date have been free to invited participants. Copies of workshop Proceedings are available from the MEND Secretariat.

TECHNOLOGY TRANSFER

Project 5.2.1a-d: Communications Plan - CIMM Lectures, Brochure, TV Series
Budget: $155,000
Sponsors: ..... CANMET $80,000
Ontario $75,000
Expenditures: $132,000
Contractors: In house, CANMET Secretariat (brochure, CIMM lectures), Topek (video)

Objectives:
To inform key audiences about the issue of acidic drainage and the new affordable technologies being developed to solve the problem; and about MEND as a cooperative initiative involving governments and industry working together towards practicable, affordable solutions.

Outputs:
Louis Sirois was nominated as CIMM Distinguished Lecturer and presented to six local CIMM Branches. The presentations were very well received.

Five thousand copies of the brochure on MEND and acidic drainage were produced and widely distributed. The brochures will continue to be distributed through the MEND Newsletter and at conferences and workshops.

A proposed television series on the mining industry, prepared by the Mining Association of Canada and ISTC was not attempted because of cost, possible duplication of programs produced by others, and by the MEND video.

Two versions of a video on MEND and control of acid mine drainage have been prepared. A long (20 minutes), "technical" video and a short (12 minute) "general public" version were produced in English and French and distributed in May 1995. The long version of the video will be targeted to the mining industry and to government agencies, the short to libraries, schools and television stations. Copies of both versions will be sent to selected groups outside Canada. The technical version of the video is being translated into Portuguese and Spanish for distribution to South America and Europe.

PREDICTION *Waste Rock Basic Knowledge (associate)*

Project Title:	**Hydrogeology of Waste Rock Dumps**
Budget:	**$50,000**
Sponsors:	**CANMET $25,000**
	British Columbia $25,000
Expenditures:	**$50,000**
Contractor:	**University of British Columbia**

Objective:

The objective of this work was to obtain a better understanding of water flow within and through waste rock piles, including its temporal and spatial variability. This would ultimately lead to improved capabilities to reliably assess and predict the long-term chemical evolution of water draining from waste rock piles a major stumbling block to the development of accurate predictive models for waste rock piles.

Outputs:

This project analysed the hydrogeological properties of waste rock piles based on a synthesis of data form four mine sites; Myra Falls, B.C., Island Copper, B.C., Elkview Mine, B.C., and Golden Sunlight Mine, Montana. Four hydrostratigraphic models were proposed to characterized waste rock piles; they differ depending upon material types and construction methods. A methodology is presented, based on kinematic wave theory, that relates the outflow hydrograph recorded in toe drains to large-scale parameters characterizing the hydraulic conductivity structure of the waste rock pile. The outflow in response to an infiltration event is treated as an integration of the outflows from different channel groups within the pile. Water transfer from the channels to the finer-grained matrix is taken account of in the analysis. Application to the Island Copper data set suggests that the approach holds promise as a means of characterizing large-scale flow processes in the waste rock pile.

Recommendations:

Further work is warranted to improve the model in its representation of channelized flow. The method should be applied to rainfall events at a number of different sites to gain insight to the relationship between hydrostratigraphy and flow responses.

PREVENTION AND CONTROL ***Subaqueous Disposal (associate)***

Project Title: Study of Submarine (Ocean) Tailings Disposal
Budget: $50,000
Sponsor: U.S.B.M
$50,000
Expenditures: $50,000
Contractor: U.S.B.M./University of British Columbia

Objective:
The objective was to establish the validity of submarine tailings disposal by completing a detailed literature review, and by compiling case histories from mine sites where submarine disposal was used.

Outputs:
Submarine tailings disposal (STD) involves technology whereby mill tailings are discharged through an engineering outfall at a location and depth selected to minimize environmental impacts (e.g. at depth in chemically unreactive low oxygen environments). Such systems have been in operation since 1971 in Canada and others are operating or are in the planning stages around the world. These STD also incorporate advanced preliminary assessment work, and comprehensive monitoring requirements to predict and then document actual levels of impact.

The final report reviews four case histories of STD from Canada and Alaska. It presents descriptions of the ore body and the milling process, the wastes produced, the engineering tailings outfalls, and data demonstrating the levels of environmental impact, for each case history.

At Island Copper Mine, on Vancouver Island, the STD system with both its positive and negative aspects is the best documented anywhere. A comprehensive monitoring program has been in place since 1970 prior to operations which started in 1971 and will continue through to closure in 1996, and possibly beyond. Where active tailings deposition and localized resuspension causes turbidity and smothers benthos there is no indication of impact on primary biological production; and natural recolonization restores a productive ecosystem within one to two years.

The other case studies included; the Kitsault molybdenum mine, near the Canadian - Alaska border, the WestGold marine placer dredging operation near Nome, Alaska, and the proposed Quart Hill molybdenum mine near Ketchican.

The report is the first of two volumes reviewing case histories of STD. The second will review existing or planned systems from around the world. It is expected that the complete set of case histories will allow the development of screening criteria for

appraisal of STD systems at new mines. These criteria will be presented at the conclusion of the second volume.

PREVENTION AND CONTROL ***Waste Rock (associate)***

Project Title: Evaluation of the Effectiveness of Reclamation Measures at Mount Washington

Budget: $1.5M

Sponsor: ..... B.C. $1.5M

Expenditures: $1.5M

Contractor: B.C. MEI

Objective:

The objective was to assess the effectiveness of various reclamation techniques intended to reduce or control acidic drainage from the Mount Washington abandoned mine.

Outputs:

The Mount Washington mine reclamation project was started by the B.C. government in 1988 following a study by a consultant that suggested 17 different options for corrective treatment. Measures that were completed in the first couple of years included: consolidation of waste rock piles on the site and placement on the larger dumps; contouring followed by covering the East Dump with a one-metre layer of compacted glacial till; addition of crushed limestone; construction of up slope diversion ditching; and installation of instrumentation. Although acid drainage from the East Dump was less than, and more stable than that of the pit, no apparent reduction in total loading from the site was obtained; and work subsequently focused on the pit area.

In 1990-91, a test section of the pit floor was totally cleaned of waste (shattered rock) to determine the acid generating characteristics of a clean pit floor; to permit the examination of bedrock mineralization; and to provide two discrete substrate conditions (clean bedrock and contoured waste) for testing of a variety of cover materials. Excavated waste was encapsulated and two cover materials were tested: thin slab reinforced concrete; and asphalt emulsions. Remote monitoring instrumentation was installed in early 1992.

Wash water samples from the surface of the "competent" pit floor yielded high concentrations of copper (>100mg/L), and sulphate (>5000mg/L). The sulphide copper concentration in bedrock chip samples from the same area was been found to be >0.8%. **There is some evidence of correlation between the wash water samples and the copper concentration at specific locations. The most promising control technique would include cleaning and sealing of the bedrock surface, grouting of the shattered pit floor and possibly insitu neutralization of groundwater flows at peak flows. Other sources of copper, mostly mining related, have been documented in the drainage basin. These contribute also to the overall copper loading and must be considered in the remedial**

action plan. Cost of the basin wide evaluation, and future minesite geohydrological studies, is estimated to be approximately $3/4 million dollars.

PREVENTION AND CONTROL ***Waste Rock (associate)***

Project Title: Segregation of Waste Rock at the Samatosum Mine
Budget: $30,000
Sponsors: ..... Minnova
$30,000
Expenditures: $30,000
Contractors: B.C. Research/Minnova

Objectives:
This project linked laboratory studies on the effectiveness of segregation of waste rock as a means to prevent acidic drainage to performance of a full-scale waste rock dump implementing that technique. The objectives included determining the effectiveness of segregating waste rock with high potential to generate acidic drainage in a dump as a means to prevent AMD generation in the long term.

Outputs:
For the control of acidic drainage, Samatosum chose to layer potentially acid generating (PAG) waste rock and mafic pyroclastics (MAF) (non net acid generating) as distinct 6m lifts in the waste rock pile. The theoretical basis for this layering was that an overlying MAF layer would release net alkalinity into downward-seeping infiltration, neutralizing acidity within the PAG layer below. Then, any net acidity migrating downwards from a PAG layer would be further neutralized by an underlying MAF layer.

To test the success of layering, five columns were constructed in a laboratory and water was continuously flushed through these columns for a maximum of approximately five years. At the end of the testwork, the layered columns had not generated net acidity. Furthermore, extrapolation of trends into the future indicated that the columns would never generate net acidity. Under field conditions, in the full-size dump layering was successful at maintaining pH-neutral to alkaline conditions in seepage to date (September 1995). The laboratory study was completed in 1994.

The combination of extensive field monitoring of the actual dumps and the five years of column leachate monitoring provided a rare opportunity to compare laboratory simulations with the resulting performance of layering as a means of ARD prevention. In 1995, MEND received approval to review and compile the existing field and laboratory data, to review the interpretations and re-interpret data where necessary, to estimate the long term success of layering, and recommend ways to improve and test layering at other mine sites (2.37.3).

Appendix D

Active Projects

Number	Titles
1.12.1b	DBARD - DataBase for Acid Rock Drainage: Continued Compilation of AMD Prediction Data
1.14.3	Mine Doyon: A Comprehensive Review
1.16.3	Critical Evaluation of Procedures to Determine the Potential of Mining Wastes to Produce Acid Rock Drainage
1.16.5	Identification of Variability in Static Test Methods
1.18.1a	Development of an Information System to Assist with the Interpretation of Static Acid-Base-Accounting Test Data
1.21.2	Laboratory and Modelling Studies of Pyrrhotite Oxidation
1.27.1a	Guide for Predicting Water Chemistry from Waste Rock Dumps - Phase I
1.31.2	Residual Weathering Products in Waste Rock Dumps
1.32.2	Pyrite Oxidation - Lithological and Mineralogical Approach
1.41.3b	Waste Rock Pile Monitoring Ontario - Laboratory and Field Measurements
1.41.4	Waste Rock Pile Monitoring - Low Acid Production (Borderline)
1.44.1	Waste Rock Pile Disassembly - B.C.
1.61.1	Permafrost - Techical Review
1.61.2	Acid Rock Drainage (ARD) Prevention and Control: Towards a Tailings and Wasterock Strategy for Using Permafrost to Manage ARD.
1.61.3	Permafrost - Cullaton Lake Data Analysis and Interpretation
2.11.1e	Peer Review on the Subaqueous Disposal of Tailings - Phase II
2.11.3d	Anderson Lake - 1995 Program
2.11.5ab	Shallow Water Covers - Equity Silver (Physical Parameters)
2.11.5c	Shallow Water Covers - Equity Silver (Geochemical Parameters)
2.11.9	Underwater Disposal Sites - Design Guidelines
2.12.1	Man-Made Lakes Disposal Sites - Louvicourt Project
2.13.2d	Monitoring of the Flooded Solbec Cupra Tailings Site
2.15.1a	A Study on Water Covers for the Decommissioning of Mine Water Disposal Sites - Noranda Technology Centre
2.15.1b	A Study on Water Covers for the Decommissioning of Mine Water Disposal Sites - CANMET
2.15.2	Metal Releases After Flooding
2.21.3a	Peer Review of Waite Amulet and Heath Steele Soil Cover
2.21.3b	Peer Review on Covers Made With Non-Traditional and Synthetic Materials
2.22.2b	Evaluation of Dry Covers Built From Mine Tailings - Field

2.23.2c A Tracer Study of Fluid and Contaminant Movement in the Upper Surface of the Thickened Tailings Disposal (TTD) Systems at Kidd Creek Mines

2.23.3b Design Parameters - Previous Envelope and Porous Surround Methods

2.25.3 Assessment of Covers for Reducing Acid Generation from the Strathcona Tailings

2.31.1c Additional Monitoring of the Composite Cover at Heath Steele

2.36.2 Hydrogeochemistry of Oxidized Waste Rock and AMD Prediction Techniques

2.36.3 Literature Review of Methods for Characterization of Waste Rock Prior to Underwater Disposal

2.37.1 Layering Different Types of Waste Rock to Create a Non-Acid Generating Composite - Case Studies

2.37.2 Review of Methods for Delaying Onset of Acidic Drainage - Case Studies

2.37.3 Characterization of Test Materials from Sa.atpsi, Column Study

3.41.1a On Site Treatment of AMD

3.41.2 Metal Sulphide Bio

3.42.2 Lime Sludge Stabilization

4.6.5b Laboratory Studies to Assess the Oxidation Potential of Waste Rock Representitive of Pile Sized Material

5.4.2a AMD/ARD Handbook - Phase I

5.6.3 Fourth International Conference on the Abatement of Acid Rock Drainage

5.7.1 MEND Newsletter

5.9 Review of MEND

Associate Projects

- Metal Transport and Immobilization at Mine Tailings Impoundments
- Subaqueous Disposal - Moose Lake (Falconbridge)
- Separation of Sulphides from Mill Tailings - Field

PREDICTION ***Chemical Prediction***

Project 1.12.1b: DBARD - Database for Acid Rock Drainage: Continued Compilation of AMD Prediction Data

Budget: $40,000

Sponsors: British Columbia $20,000

CANMET $20,000

Expenditures: $25,000

Manager: G. Feasby, CANMET

Contractor: University of British Columbia

Objective:

This project will furthur develop the existing database for acid rock drainage prediction data, DBARD, through:

- additional input of selected available static and kinetic test data;
- further development and user accessibility of the software; and
- ongoing maintenance and distribution.

Status:

The database, DBARD, was developed over the last two years to accept, store and retrieve relevant data from acid prediction testwork, including data from one-time or repetitive laboratory experiments and field tests. Version 1.0 of DBARD was a simplistic database with rudimentary routines for data entry which was not released. The database was greatly expanded in Version 2.0 with improved data handling and editing, but little data was actually entered.

Since April 1993, the database has resided at the University of British Columbia under the auspices of the Chair in Mining and the Environment. During this time the focus was on data input. The database now contains information, although not comprehensive, on mine component characterization and AMD prediction for 119 mines in British Columbia (1.12.1a).

The software was successfully transferred from the dBase II DOS based platform to Paradox, Version 5.0, a Windows based platform. The Windows environment ensures that data may be inputed or extracted in a more user-friendly manner. Associated user's manuals are also being upgraded. Direct access to the database through the MEND Internet site is being considered.

Over the next year, selected data have been entered from the rest of Canada, and internationally, to ensure that a wide range of different and comprehensive prediction

datasets are included. The database is in the process of being finalized and should be completed in 1996.

PREDICTION *Modelling*

Project 1.14.3: Mine Doyon: A Comprehensive Review
Budget: $74,500
Sponsors: ..... CANMET $37,250
Québec $37,250
Expenditures: $45,650
Manager: C. Weatherell, CANMET
Contractor: Geocon

Objective:
The south waste rock dump at Mine Doyon, Cadillac, Québec has been generating acidic drainage since 1985, two years after the dump was started. Acid generation increased steadily from 1985 to 1988; and since 1988 the dump has been generating strong acidic drainage which is presently collected and treated with lime. Between 1991 and 1994 the south dump was the subject of extensive investigations and studies carried out through MEND primarily by le Groupe de recherche en géologie de l'ingénieur (GREGI) at l'Université Laval. The results of these studies were issued to MEND in a series of ten reports. The objective of this project was to complete a technical review of the monitoring data collected to 1994 and the associated site assessment date.

Status:
A peer review of the studies carried out at the south dump by a designated group of expert consultants (Peer Review Team) was carried out under five separate technical components identified as; (i) hydrology, (ii) geotechnical and hydrogeology, (iii) geochemistry and mineralogy, (iv) microbiology and (v) predictive modelling. The Peer Review Team completed a technical and scientific review of the Doyon reports with particular reference to providing a critique of strong and weak points, identifying new information and understanding developed from the studies and suggesting areas for future work.

The overall conclusion of the review is that the Mine Doyon case study has advanced the understanding of some specific technical issues, however, the peer review identified weaknesses in the technical approaches used for the study. The peer review also identified inconsistencies and technical errors in the reports which should and will be corrected.

A draft report was received in late 1995 and is undergoing review by the original authors of the Mine Doyon series of reports. The final report will be completed and available in 1996.

PREDICTION ***Chemical Prediction***

Project 1.16.3: Critical Evaluation of Procedures to Determine the Potential of Mining Wastes to Produce Acid Rock Drainage

Budget: $30,000

Sponsors: Environment Canada $20,000

HBMS $10,000

Expenditures: $30,000

Manager: B. Godin, Environment Canada

Contractor: University of British Columbia

Objectives:

To conduct a rigorous evaluation of the range of application and shortcomings of static prediction procedures, principally the standard acid-base accounting test, currently used by the Canadian mining industry and regulators to facilitate mining waste management and permitting decisions. Also, to provide recommendations for the use of static test procedures and their interpretation for acid rock drainage prediction to assist in the prevention or reduction of pollution to receiving waters.

Status:

An investigation was carried out to critically evaluate methods used to determine the neutralization potential of mining waste samples as part of prediction testing for acid rock drainage. In particular, the use of the standard acid base accounting method of Sobek to measure the neutralization potential of a sample was assessed. Results obtained by this method were compared with those from a modified ABA procedure and with results calculated from CO_2 analysis. In addition, variations in NP determinations obtained by performing the Sobek procedure using different acid additions based on different fizz ratings for the same sample were determined. Comparisons of the results of NP determinations were carried out. The reporting of the results of NP determinations carried out by many laboratories do not include the exact conditions used, so that proper interpretation of data and the possible degree of overestimation, if it exists, cannot be assessed if variations in procedure are inadvertently or deliberately used by the laboratories. 112 waste rock and tailings samples from 12 operating or proposed mines in 5 countries were used in the test program. In addition, 8 certified reference standard materials were supplied by CANMET for the study.

Back titration curves showed that an indication of the minerals contributing to the NP value obtained can be determined from the profile of the curve. Mineralogical characterization of a subset of the 112 samples has yet to be completed.

Project 1.16.5: Identification of Variability in Static Test Methods
Budget: $50,000
Sponsor(s) To be determined
Manager: To be determined
Contractor: To be determined

Objectives:

The objectives of this project are as follows:

- To carry out an evaluation of the range of application and the shortcomings of static potential procedures currently used by the Canadian mining industry for the assessment of mining minerals;
- To provide recommendations for static test procedures and their interpretation for acid rock drainage prediction;
- To evaluate methods for calculating the neutralization potential of waste minerals, including total and available alkalinity; and
- To recommend if possible alternative or additional analytical methods to evaluate the neutralizing potential of waste rock materials.

Status:

A number of methods are commonly employed to estimate the degree to which a mine waste will produce acid. Acid-Base Accounting (ABA) takes into account a number of factors such as: sulfur content; readily available alkalinity in the form of reactive carbonates (calculated by CO_2 release upon acidification of a sample); chemical composition of the host material; static test results and others. The results of these data are assembled and values of neutralization potential NP and acid potential (AP) are determined. Depending upon the ratio of these values a host material may be considered as acid-producing or non-acid producing. The determination of these values depends upon a number of factors that may or may not be accounted for during the test procedures. Current methods to determine (NP) are subject to extremes in variability causing great ambiguity in determined NP and calculated net NP values. Some of this ambiguity may be accounted for in the actual test methodologies while others may be attributed to interpretation of the results obtained from these procedures. Also, the effects of various mineral phases on NP has yet to be adequately determined.

A scope of work is currently under review by Prediction committee members to address the ambiguities associated with current ABA methodologies. A formal link to the mineralogy of the host material is planned as is linkage of static and kinetic tests to field data.

PREDICTION ***Chemical Prediction***

Project 1.18.1a: Development of an Information System to Assist with the Interpretation of Static Acid-Base-Accounting Test Data

Budget: $50,000

Sponsor(s): To be determined

Manager: To be determined

Contractor: To be determined

Objective:

The specific objective of the proposed work is to develop a simple information system to facilitate the analysis of acid-base-accounting (ABA) test data. The system should take into account ABA, chemical and mineralogical data as a minimum and recommend to operators the necessary steps required to minimize the risk associated with ARD.

Status:

The ability to provide a comprehensive, scientific, technical and economic basis to predict with confidence the long-term management requirements for reactive mine waste is one of the main objectives of the MEND program.

The short and long-term effects of acidic drainage, specifically from reactive waste rock at mine sites has become a serious concern. Current methods to determine neutralization potential (NP) are subject to extremes in variability causing great ambiguity in determined NP and calculated net neutralzing potential (NNP) values. These ambiguities lead to extreme difficulty in the interpretation of the results of ABA test data and potentially incorrect conclusions regarding the potential for the material to be acid generating.

The proposed work is meant to simplify the interpretation of existing ABA procedures by the use of an information system to analyze all data relevant to ABA (NP, mineralogical, chemical analytical etc.). The system should take a step-wise approach where operators are informed of the uncertainty at each step with the amount of data available and recommendations to reduce the uncertainty are given to the operator. The information system is not meant to be a predictive model nor would it be used for decision making but rather as a tool for data analysis.

A draft scope of work is currently being reviewed and modified by the Prediction committee.

Project 1.21.2: Laboratory and Modelling Studies of Pyrrhotite Oxidation

Budget: $110,000

Sponsors:

INCO $30,000

Noranda $20,000

Ontario $30,000

CANMET $30,000

Expenditures: $59,9800

Manager: S. Ahmed, CANMET

Contractor: University of Waterloo

Objective:

The purpose of this study is to quantify pyrrhotite oxidation in relation to relevant environmental conditions and to develop models to describe these reactions in tailings and waste rock.

Status:

Numerous pyrrhotite samples from different localities in North America were obtained to determine if differences in impurities such as Ni, Co and Cu ions that have substituted for Fe in the pyrrhotite structure have an effect on oxidation rates. All samples have been cleaned and examined by X-Ray Diffraction (XRD) analysis. The cleaning procedure was revised to ensure the complete removal of fines. Surface areas measured by Brunauer-Emmett-Teller (BET) analysis are approximately 5 times higher than estimated geometric areas most likely due to surface irregularities on pyrrhotite particles. Surface areas are also dependant on the pyrrhotite variety.

The quantitative analysis of the crystallographic determination of the monoclinic and hexagonal pyrrhotite fractions has been revised. The new procedure is based on a guassian analysis of both of the monoclinic peaks on the XRD spectra. Elemental analysis by chemical digestion followed by inductively coupled argon plasma (ICAP) are being conducted.

The results to date show that, unlike pyrite, pyrrhotite dissolves in the absence of oxidants and that in solutions with pH values between 2 and 3, this oxidant-free dissolution occurs at rates similar to abiotic pyrite oxidation. Biological rates based on iron release appear to be lower than oxidation rates by ferric iron alone. When sulphate release is considered, however, biologic rates are highest relative to other oxidation reactions. Results suggest that the degree of oxidation of the sulphide sulphur in pyrrhotite depends on the oxidant present and the rate of reaction. Columns studies were initiated in the fall of 1995.

PREDICTION ***Modelling***

Project 1.27.1a: Guide for Predicting Water Chemistry from Waste Rock Dumps - Phase I

Budget: $35,000

Sponsors: ..... CANMET $17,500

British Columbia $17,500

Expeditures: $14,990

Manager: C. Weatherell, CANMET

Contractor: Norecol, Dames and Moore

Objective:

The objective of this project is to consider the empirical approach to complement the existing deterministic models used for predicting geochemical parameters in existing waste rock dumps. One approach to empirical modelling is to characterize seepage with the expectation of determining the potential future behaviour of the waste rock pile and the behaviour of different waste rock dumps with a similar composition. The case studies put forth for the current work will be used to independently verify the applicability of this approach. Other statistically sound mathematical techniques were applied to further verify the applicability of an empirical approach.

Status:

It is concluded based on this study that the empirical approach proposed by Dr. Kevin Morin and others is valuable for large datasets but less reliable predictive relationships are likely to be obtained for small datasets. Concentrations of many metals can be predicted from conductivity and sulphate using simple bivariate regressions while other predictors such as temperature and ORP may also be useful, and inexpensive to measure. Regression relations cannot be applied to new or unmonitored sites. However, they can be used to reduce monitoring costs and/or increase sampling frequency. Multivariate techniques such as Principal Component Analysis (PCA) can be used to screen the data and identify relationships among the variables. Information from the screening can be used to select variables for further analyses, using least squares regression or alternative statistical methods. The utility of the approach is enhanced if sampling is conducted following a routine schedule by trained personnel using well-defined protocols. Routine quality control (QC) is often missing and should include as a minimum field duplicates and blanks. Geochemical evaluation of the data indicates that the strong correlation of many variables in the datasets is due to the link between sulphur oxidation, release of acid and leaching along drainage pathways.

The next step in this type of modelling should be to develop a better understanding of the mineralogical controls on dump leachate chemistry.

Project 1.31.2 Residual Weathering Products in Waste Rock Dumps

Budget: $40,000

Sponsors: British Columbia $20,000

Placer Dome $10,000

Expenditures: $19,910

Manager: W. Price, B.C. Ministry of Employment and Investment

Contractor: University of British Columbia

Objective:

This project is assessing weathering products retained in a waste rock pile from a dump-leach mine site. Specific objectives are: the identification and characterization of the weathering products; the development of probable mechanisms that relate bulk mineralogy to the secondary products formed; and the estimation of the reactivity/stability of these secondary products under differing environmental conditions.

Status:

Samples were collected from one rock pile and three different weathering regimes as defined by acid leaching activity at the time of sampling. Fine fractions were isolated and analyses performed to date include: paste pH, particle size analysis, Leco-S, total major and minor elements (XRF), bulk mineralogy (XRD), SEM/EDX on selected samples, selective dissolution extractions, sequential extractions, and turbidimetric SO_4^{2-} where possible. Extractions were analyzed using AAS or ICP-AES. MINTEQA2 is being used to determine the possible mineral phases controlling the observed extractable metal concentrations.

The fine fraction analysis by XRF and XRD are dominated by elements and minerals associated with the host rock. Analyses indicates there is a correlation between morphological features indicative of weathering. Analysis of water extractions indicates that the dominant elements removed are, from high to low, S (SO_4^{2-}), Ca^{2+}, Mg^{2+}, and Cu^{2+}. As expected, water-extractable-Ca^{2+} and -SO_4^{2-} are very closely correlated. Results suggest there is little jarosite, schwertmannite, or sulphides on these samples and that most of the retained S is in CaS_{O4}. MINTEQA2 indicates the ion activity products of gypsum, anhydrite, cupric ferrite and a variety of Fe oxides have been exceeded.

The next phase in this project will be to examine the meta-stability/reactivity of the stored weathering products. Various lixivants will be used to test the stability of coatings using a batch-style experiment. Secondly, a wet-cycle cycling experiment will be performed to examine the solubilization of coatings. This project is expected to be completed in the winter of 1996.

PREDICTION ***Waste Rock Basic Knowledge***

Project 1.32.2: Pyrite Oxidation - Lithological and Mineralogical Approach
Budget: $40,000
Sponsors: British Columbia $20,000
Homestake Canada Inc. $5,300
Expenditures: $19,084
Manager: W. Price, B.C. Ministry of Employment and Investment
Contractor: University of British Columbia

Objective:
To investigate the applicability of detailed lithological and mineralogical characterization to the prediction of acid rock drainage.

Status:
Determined NP and calculated CaNP from acid volatilized CO_2 data agree well for both Eskay Creek and Mount Milligan samples. This suggests that the available buffering capacity results from carbonate and not silicate minerals. Eskay Creek samples showed that generally footwall rhyolite breccia is potentially acid generating while hanging wall basalts are not. The acid generating potential of rhyolite flow and massive rhyolite samples is uncertain.

While laboratory weathered samples were selected to minimize the presence of sulfides other than pyrite, these results indicate that other sulfides were present in some samples and therefore oxidation rates may not be representative of pyrite oxidation only. Based on the previous modified acid base accounting that was conducted on samples, 6 of the 10 Eskay Creek samples weathered were predicted to be potentially acid generating, two potentially acid neutralizing and two of uncertain potential. Laboratory weathering resulted in 8 of 10 generating acid in 121 days of weathering, including one with an acid neutralizing potential and one with an uncertain potential. Of the two samples remaining, one with an acid neutralizing potential went acid within the 121 days of weathering as did the other of uncertain acid generating potential. Similarly from Mount Milligan samples, 9 of 11 samples were acid generating after 121 days of weathering. The two remaining samples that remained near neutralizing were classified as potentially acid generating. Several of the potentially acid generating samples and the one sample of uncertain potential were delayed in reaching acidic conditions. Based on these results, modified acid base accounting has adequately predicted the acid generating potential of almost all samples. In addition, acid volatilized CO_2 analysis predicted the presence of buffering by silicates which was confirmed in laboratory weathering by the presence of high concentrations of dissolved sodium, calcium, potassium and magnesium. The final draft of this M.Sc. thesis is expected by April 1996.

Project 1.41.3b: Waste Rock Pile Monitoring Ontario - Laboratory and Field Measurements
Budget: $290,000
Sponsors: ..... CANMET $115,000
Ontario $115,000
INCO $60,000
Expenditures: $209,050
Managers: M. McCann, INCO/C. Weatherell, CANMET
Contractor: Golder Associates

Objectives:
The primary objective of this project is to obtain a healthy database of waste rock information that can be correlated to existing rock pile information to assist the understanding of the future behaviour of waste rock piles with an emphasis on predictive modelling. Also, the effectiveness of the Waste Rock Sampling Manual developed by MEND (4.5.1b) will be assessed.

Status:
A thorough review of all relevant previous work was conducted. Four boreholes were drilled in the waste rock pile to bedrock. A fifth borehole was drilled approximately 1.5km northwest of the waste rock pile to obtain representative background water quality data. Due to the high amount of void spaces in the pile, significant amounts of solid samples were not retrieved during the drilling process. Borehole instrumentation consists of two PVC wells, thermistor strings and gas sampling ports mounted through the casings. Backfill material consisted of silica sand, a bentonite hole plug and -10mm gravel.

Three test pits were dug to a depth of approximately 4.6m near each borehole to have rock types approximately similar to those found in the boreholes. Lysimeters were installed in the pits to collect recharge water that percolates down through the waste rock pile. A collection pipe and riser were installed and the test pits carefully backfilled with selected waste rock. The faces of the test pits were videographed and photographed to obtain an estimate of the size distribution for the material in the entire waste rock pile by using the GOLDSIZE program developed by Golder. A road cut to provide access to a main seepage point exposed a large face of the pile interior and provided a good representation of the cross-section of the pile. Samples were taken and field tests performed. This face will be monitored throughout the program.

Monitoring data is being collected on a continual basis. Two laboratory columns are also being monitored as part of a 20 week kinetic study.

PREDICTION ***Waste Rock Basic Knowledge***

Project 1.41.4: Waste Rock Pile Monitoring - Low Acid Production (Borderline)
Budget: $200,000
Sponsor(s): To be determined $200,000
Manager: To be determined
Contractor: To be determined

Objective:
The primary objective of this project is to obtain fundamental information from a waste rock pile that has either not yet produced acid or has been predicted to not be acid generating.

Status:
The development of useful predictive techniques for masses of acid generating waste rock depends on a thorough understanding of the basic chemistry and physics of these piles. Since these waste piles are often not similar in composition, mineralogy, size, size distribution, location, history etc., the fundamental characteristics of each will differ. This leads to varying behaviours with respect to acidic drainage quality and flux.

In order to ensure accurate predictions of future waste rock pile behaviour, the fundamental characteristics of several types of waste rock piles must be well documented and thoroughly understood. A third type, namely a low acid production pile, is proposed to gain insight as to the mechanisms responsible for the low flux of acidic drainage produced.

This project will rely on the experience from past and current projects and on the Waste Rock Sampling Manual (4.5.1b).

A waste rock pile with the required characteristics is presently being sought. The monitoring of such a waste rock pile would extend into post-MEND.

** Project not yet started; may be withdrawn in 1996 because of other higher priorities.*

Project 1.44.1: Waste Rock Pile Disassembly - B.C.
Budget: $30,000
Sponsor: Homestake Canada
$35,000
Expenditures: $35,000
Manager: W. Napier, Homestake Canada Inc.
Contractor: Morwijk Enterprises

Objective:
The specific objective of the proposed work is to provide qualitative and quantitative information on mass transport and water infiltration within a waste rock pile.

Status:
The prediction of water chemistry depends in part on the movement of water through waste rock. Waste rock pile hydrology is determined by processes and factors including: precipitation, annual and event runoff, evapotranspiration, dumping practices, infiltration, saturated flow rates, gas flow and topography. Waste rock pile hydrology is poorly understood partly because of the scarcity of available data and partly because of gaps in the fundamental knowledge in the areas of chemical and hydrological processes. The methods and patterns of water movement through waste rock piles can be used as an indicator of the complexity of developing coupled geochemical-hydrological predictive models.

Although there are some lysimeter tests described in the literature that provide information on mass transport and infiltration, there is little documentation describing the hydrogeology within a real waste rock pile as confirmed by the disassembly of a rock pile. Only one such study has been identified. A relatively small waste rock pile (70,000 tonnes) in British Columbia will be disassembled and moved to a subaqueous storage site during the spring of 1995, affording an excellent opportunity for this work. Still photographs and video recordings of the waste rock dump during disassembly showing relevant features of water transport (via staining) secondary mineral deposits, where applicable will be provided. Secondary mineral products obtained from inside the waste rock dump during disassembly will be identified. A final report detailing all qualitative and quantitative results obtained throughout the project including; secondary mineral formation in the waste rock pile, observations pertinent to mass transport and water infiltration observed during the test work and disassembly of the waste rock pile and finally conclusions as to the mechanisms of mass transport and water infiltration in the waste rock pile.

PREDICTION ***Permafrost***

Project 1.61.1: Permafrost - Technical Review
Budget: $32,000
Sponsor: ..... DIAND
$32,000
Expenditures: $32,000
Manager: M. Barnett, DIAND
Contractor: CANMET

Objectives:
The objective of this work is to present a summary report of information, data, and critical parameters in two primary areas. These are:

- the role that ice and snow cover plays in the water cover option for the disposal of reactive tailings; and
- the role of permafrost in the long-term management of acid generating tailings.

Status:
There is a wealth of literature on the characteristics of ice covers and permafrost and their potential impact on tailings waste management in the north.

This review and assessment will provide a basis upon which to consider the design and implementation of laboratory and field studies to evaluate the effects of ice on water covers. An evaluation of the use of permafrost as a dry cover by freezing tailings permanently will also be included. Brief overviews of the climatic conditions in northern Canada and the associated level of mining activity in the Yukon and Northwest Territories will be presented. The application of wet and dry barriers as control technologies will be discussed in the context of assessing the impact of northern conditions on the water cover option, and the impact of permafrost as a dry barrier on tailings reactivity. The role of ice and water cover will be reviewed with considerations to; risks to structures and barriers, the potential impact of ice scouring on material disposed subaqueously, the potential thickness of ice covers, snow fences, and the role of snow removal versus accumulation to ice thickness.

The impact of permafrost, specifically on the freezing of sulphide bearing mine wastes, will be addressed. The characteristics of continuous and discontinuous permafrost will be introduced. The impact of in situ temperatures, hydrology, and permeability on chemical and bacterial activity is further developed. The characteristics of the active freeze-thaw layer will be addressed as will the methods for promoting permafrost. This project will result in a concise compendium of currently available permafrost knowledge that may be employed for developing mine waste management strategies for northern climates.

Project 1.61.2: Acid Rock Drainage (ARD) Prevention and Control: Towards a Tailings and Wasterock Strategy for Using Permafrost to Manage ARD.

Budget: $50,000

Sponsor: ..... DIAND

$50,000

Expenditures: $50,000

Manager: M. Barnett, DIAND

Contractor: Agra Earth and Environmental Ltd

Objectives:

The objectives are to review and report on the circumpolar permafrost technology experience as a control mechanism for northern mines, including available kinetic data; and to design and report a generic 2-3 year field program for tailings and waste rock, including parameters to be monitored and their frequency.

Status:

Acid generation within mine tailings has been noted at two minesites in Canada's permafrost regions. Acidic seepage and runoff has also been documented in the natural permafrost environment. Cold temperature leach column testing shows that acid generation is slowed down but not reduced to negligible levels at temperatures approaching freezing.

Processes related to acidic drainage in cold climates have been reviewed. Important processes that require further study include the influence of sulphide minerals and process chemicals on unfrozen water content, thaw degradation due to oxidation, reaction rates at low temperatures, and frozen hydraulic conductivity of saturated and unsaturated mine waste material.

Control strategies that take advantage of permafrost conditions include freeze and climate control. Freeze control of tailings appear to be a viable strategy however there is a need for more cost effective insulating cover designs and a more thorough understanding of frozen tailings thermal properties. There is potential for using the beneficial permafrost climate for achieving modest engineering control strategies in waste rock dumps using zoning of different material types.

Implementation of reliable and economic AMD control strategies are impeded by a lack of understanding of important cold weather processes and demonstrated performance. A program for researching freeze control of mine tailings is scoped out. Development of freeze control and climate control strategies for mine waste rock requires a much better understanding of mass transfer and geochemical processes acting within waste rock dumps.

A fairly substantial effort will be required to achieve this level of knowledge. A general program of research.

Project 1.61.3: Permafrost - Cullaton Lake Data Analysis and Interpretation
Budget: $10,000
Sponsor: Homestake Canada Inc. $10,000
Expenditures: $25,000
Manager: W. Napier, Homestake Canada Inc.
Contractor: Laurentian University

Objectives:
To evaluate the oxidation and leaching characteristics of the Cullaton Lake B and Shear Zone tailings at low temperatures.

Status:
Cold temperature column leaching tests at 2° and 10°C were conducted for Cullaton Lake B and Shear (S) Zone tailings to evaluate their oxidation and leaching characteristics at low ambient temperatures. The tests were an extension of the earlier room temperature study in which both B and S-Zone tailings produced acidic drainage under laboratory simulation conditions.

Oxidation and acid generation occurred in both B and S tailings columns at low (2°C) and intermediate (10°C) temperatures. The rate of acid generation was lower and its onset was delayed at these temperatures compared to 25°C. For B-Zone tailings, containing relatively high sulphide (2.34% S), high total available alkalinity (41.5kg CaCO3/tonne tailings) and a large negative net neutralization potential (NNP of -31.65kg CaCO3/tonne tailings), the acid generation rate at 2°C was low with the result that there was a reasonable degree of acid neutralization and acid drainage was prevented during most of the leaching period at that temperature. The overall impact of acidic drainage from B-Zone tailings was lower colder temperatures. The tailings retained appreciable amounts of moisture (85-100% saturation) that limited the oxidation to the upper, exposed, layer, thereby controlling the acidity and reducing the impact. The S-Zone tailings were also characterized by high moisture retention and poor drainage that limited the oxidation and overall impact to the upper surface. In contrast to the results from the B-Zone tailings, the S-Zone tailings exhibited no net reduction in acidic drainage at lower temperatures reflecting the low total available alkalinity in the S-Zone tailings.

It was recommended that the data from these leaching studies be further examined and analyzed to obtain acid generation and metal loading rates at the three study temperatures (25°C, 10°C and 2°C). Quantitative microbiological studies should also be undertaken to distinguish between chemical and biotic oxidation at low temperatures.

PREVENTION AND CONTROL. Underwater Disposal

Project 2.11.1(e): Peer Review on the Subaqueous Disposal of Tailings - Phase II
Budget: $30,000
Sponsors: ..... CANMET
$31,000
Hudson, Bay Mining and Smelting (HBM&S) $9,000
Expenditures: $ 40,000
Manager: W. Fraser, HBM&S
Contractors: P. Sly/Resources Futures International

Objective:
Scientific and regulatory review and planning is a major part of the program, and is assisting in achieving a fair and objective study of the concept and methodology for subaqueous disposal of reactive tailings in lakes. The objective of this project is to assess the work undertaken over the past three years in context with the original points of concerns identified in the first peer review (2.11.1d).

Status:
The general conclusions from the draft report are that: the literature study on biological uptake of metals is closely focused and up to date; the report provides background information but there are still uncertainties about mine effects on Anderson and Buttle Lakes; an acid-base mass balance has yet to be completed on Anderson; there are inconsistencies in peeper and core porewater data which may have occurred during field installation and retrieval; and the QA/QC program did much to improve the 1993 data from both lakes, but there were inconsistencies with Fe, Mn and Zn data.

The main technical issues identified in this review are; the extrapolation of estimates from a small area to the whole lake system; and the biological component which is considered site specific. For this reason it was decided long ago that biological impacts would not be included in the MEND subaqueous studies.

In general, the program was a significant step forward but some problems persist. The data supports the conclusion that very little recycling of metals occurs from buried tailings. The question that remains on the release of metals is how small, since significant effects may occur with small releases.

A second draft report is in preparation, taking into account the discussions from the second technical overview meeting with regulators last June in Vancouver, the comments received from the MEND reviewers, and the additional data generated from Anderson Lake (2.11.3d). The report will be specifically directed to a broad audience, gathering the results

and assessments of the two lake studies in a balance consideration of the appropriateness of subaqueous disposal of tailings.

PREVENTION AND CONTROL Subaqueous Disposal

Project 2.11.3d: Anderson Lake - 1995 Program
Budget: $ 55,000
Sponsors: Hudson Bay Mining & Smelting $ 30,000
Manitoba ..... $ 12,500
CANMET ..... $ 12,500
Expenditures: $ 45,000
Manager: W. Fraser, HBM&S
Contractors: Rescan Environmental/ASL Labs

Objectives:
The objectives are to collect additional water quality data in the absence of active tailings deposition and, after start-up, to assess the impact of placing tailings in Anderson Lake. The water quality data are interpreted with the framework of an ancillar data set derived from two weather stations located near the lake and thermistor strings both within the lake water column and sediments.

Status:
Anderson Lake was used as an active disposal site through to 1994 and was restarted in late 1995. As part of the continuing evolution of the subaqueous program, it was suggested that the usefulness of the existing geochemical data set for Anderson Lake could be enhanced through a better understanding of the physical dynamics of the lake. At a Planning committee meeting it was decided that collection of additional water quality data prior to the commencement of tailings deposition and after removal of the mine rock road adjacent to the lake would further enhance confidence in several of the conclusions drawn from the study. Also, Following start-up, an opportunity existed to assess the relative influence of all sources on lake water quality.

Data from two weather stations have continuously been collected to quantify the meteorological effects on the lake hydrology. In addition, two thermistor arrays (eight thermistors each) were deployed in Anderson Lake, one in the water column to assess the physical evolution of the water column with particular reference to impact on water quality and the second at the sediment-water interface to assess the thermal evolution of the interfacial sediments specifically with regard to thermally-induced advective fluxes. Analyses will focus on water quality while drawing on meteorology and hydrography data to support hypotheses.

The data indicate improved water quality from August, 1993 to the beginning of the study but show degradation immediately prior to the reintroduction of tailings into the lake. It is suspected that removal of the acid-generating material from adjacent areas may have exposed leachable material which is being flushed into the lake. This supposition is supported by

meteorologic data which indicates that the deterioration of water quality is coincident with enhanced precipitation following an unusually dry summer. The information generated by this study will be presented in an overall Anderson Lake report which will be available in 1996 (2.11.3abcd).

PREVENTION AND CONTROL Underwater Disposal

Project 2.11.5ab: Shallow Water Covers - Equity Silver (Physical Parameters)

Budget:	$80,000
Sponsors:	CANMET $37,800
	Placer Dome $44,000
Expenditures:	$74,000
Manager:	J. Robertson, Placer Dome
Contractor:	Hay and Company Consultants Inc.

Objective:

The objective of the project is to develop a comprehensive database of key, physical parameters which will enable the development of design guidelines. The intent of the sampling program is to collect pertinent data and to use the Equity tailings site as a template to illustrate the dynamics of several of the key physical variables for shallow water covers.

Status:

The Equity Silver tailings pond is one of the first sites to close that employed water covers (cover of 1 to 1.5m depth) over fresh tailings. Several assumptions were used during the design of the impoundment and this is an opportunity to return to the closed-out site and complete an engineered evaluation on the effectiveness of shallow water covers. The project deals with the physical attributes of shallow water cover which impact the geochemical stability, namely the depth of the water column covering the tailings, the size distribution of the tailings, and the absence of bedforms at the sediment water interface.

A field program to collect baseline physical data at Equity was completed in September 1995. A bathymetric survey of the pond at a nominal spacing of 50m and the production of a bathymetric contour map using Digital Terrain Modelling (DTM) software was completed. Extensive observations of the morphology of the bed relative to the overlying water depth suggest that wave mobilization of sediments at the bed, over the time period since deposition, occurs to at least a water depth of 1.3 m but does not occur at a water depth of 3.4m. A sediment sampling program, consisting of 13 samples from each of 3 separate locations in the pond to characterize the grain size distribution and submerged weight density of the sediments within the pond was completed. A collection of six sediment cores to evaluate the stratigraphy of those sediments was also obtained.

The physical data collected at Equity will provide baseline information on the physical characteristics of the pond which are key to studying the viability of shallow water covers for acidic drainage control. The baseline information is to be used to evaluate the depth of water required in the cover to ensure that the bed will be physically stable enough to allow the geochemical gradients needed to inhibit acid generation.

PREVENTION AND CONTROL Underwater Disposal

Project 2.11.5c: Shallow Water Covers - Equity Silver (Geochemical Parameters)
Budget: $115,000
Sponsor: ..... CANMET
$120,855
Expenditures: $110,000
Manager: J. Robertson, Placer Dome
Contractor: Rescan Environmental Services Ltd.

Objective:
The objective of the project is to develop a comprehensive database of key, chemical parameters which will enable the development of design guidelines. Tailings reactivity will be addressed using high-resolution observations of trace metals and other sensitive indicators of chemical reactivity within the interstitial waters, and across the sediment-water interface.

Status:
Recognizing that lake disposal of reactive tailings is a less common management technique for preventing acid generation than disposal into man-made tailings impoundment, this study is an attempt to extend the geochemical database to encompass the latter. Specifically, the Planning committee requested an evaluation of the geochemical stability of the Equity tailings pond sediments as a start for the development of the guidelines document.

The study employed a combination of sampling methodologies: water column sampling and profiling, collection of cores, as well as the use of dialysis-membrane array-samplers (peepers). Interstitial waters from core segments will not be sampled and analysed (as peepers have now been fully validated); instead peepers were used solely for high resolution sampling of interstitial waters.

The study, initiated in late August, was designed to meet the following objectives:

- assess the hydrographic and chemical status of the water column in the pond;
- determine the distribution of dissolved metals, cyanide, sulphate and metabolites in interstitial waters, and to relate these to the chemical composition of the solid phases;
- use the pore water data to provide an estimate of the flux of metals into or from the tailings sediments;
- use the solid-phase, pore water, and water column chemical and hydrographic data to interpret controls on the chemical behaviour of the submerged tailings; and,
- compare the results obtained in this study to previous work.

Preliminary data suggest that tailings are a heterogeneous admixture of several mine waste materials. Of particular interest are the data for arsenic and antimony which display an

efflux and influx respectively. Dissolved oxygen is quantitatively consumed within a few centimetres of the interface; profiles suggest the rate of oxidation is low.

Project 2.11.9:	Underwater Disposal Sites - Design Guidelines
Budget:	$50,000
Sponsor:	To be determined
Expenditures:	$0 (not started)
Managers:	J. Robertson, Placer Dome/W. Fraser, HBM&S
Contractor:	To be determined

Objective:
The final objective of the evaluation of existing underwater disposal sites is the development of a guidelines document to use this method for general disposal of reactive tailings.

Status:
A planned outcome of the subaqueous disposal program is to develop a guidelines manual on how to employ the technique for final disposal of reactive tailings underwater. Water cover will minimize the transport of oxygen, and subsequently limit acid generation. Systematic evaluation of existing sites will provide a basis for assessing the overall effectiveness and developing a guidelines document for underwater disposal techniques. Several projects are currently underway at the Equity tailings site (2.11.5) which is being used as a template to illustrate the dynamics of several key physical and chemical variables and the results from these studies are needed for the development of the manual.

The acceptance of this promising method of acid drainage control is a prerequisite to the development of the final objective of a design and application guidelines document. This document will present the technology that has been established by MEND and would flag the site specific issues of concern. Several important steps remain before beginning the development of the guidelines.

Scientific review and planning is a major part of the program, and is assisting in achieving a fair and objective study of the concept and methodology for subaqueous disposal of reactive tailings in a lake. A meeting of the Subaqueous Disposal Planning committee is planned for June 1996 to discuss the details of the guidelines document. This important meeting will discuss the inclusion of biological factors and political issues in the guidelines, will review the status of the physical/chemical parameters projects at Equity, and will attempt to identify who is in the best position to prepare such a document.

Project 2.12.1: Man-made Lakes Disposal Sites - Louvicourt Project

Budget: $500,000

Sponsors: ..... CANMET $342,000

Teck..... $35,000

Aur Resources $83,000

Noranda Technology Centre (NTC) $35,000

Expenditures: $50,000

Manager: M. Filion, Teck

Contractors: Golder / CANMET

Objective:

The objective of the field and laboratory project for the Louvicourt man-made lake tailings impoundment is to demonstrate the effectiveness of shallow water covers as a permanent means of preventing the oxidation of sulphide minerals and the consequent formation of acidic drainage.

Status:

Underwater disposal of mine wastes (tailings and waste rock) in man-made lakes is presently an option favoured by the mining industry to prevent the formation of acidic drainage. Because of the potential controversy associated with using natural lakes for subaqueous disposal of tailings, there is considerable interest in evaluating whether artificial basins offer similar advantages to natural lakes. Artificial or man-made basins provide substantially different conditions (e.g. shallow water cover, exfiltration) for the management of reactive tailings as compared to lakes. There are numerous sites where tailings have been deposited in a partially or completely submerged state in conventional tailings areas. However, there have been no geochemical studies, similar to those carried out for natural lakes (2.11.1), undertaken for these artificial basins.

The contract was awarded in May 1995. The field design manual or tender package for the construction of the cells was completed in August. Three proposals were received in September and the average cost of construction was almost 2.5 times the original estimates. Because of numerous delays caused by other construction projects at the site and the early winter it was decided to defer the construction of the cells until 1996. Instrumentation purchases and other preparatory work were completed. Results from the field component will, unfortunately be delayed one year and may not be part of the subaqueous disposal guidelines document.

The laboratory column studies are designed to assess shallow water covers (300mm and 1m to compare) in relation to flooded tailings covered with 300mm of organic material or sand.

Oxygen diffusion, sediment erosion, oxidation kinetics, the rate of residual and reaction products migration via surface and groundwater flow regimes and modelling downstream water quality and metal loadings will be completed. Humidity cells testing is also underway.

PREVENTION AND CONTROL Wet Barriers

Project 2.13.2d:	Monitoring of the Flooded Solbec Cupra Tailings Site
Budget:	$150,000
Sponsors:	Cambior $27,000
	Quebec $92,000
Expenditures:	$90,000
Manager:	L. Bienvenu, Ministère des Ressources naturelles (MRN) du Quebec
Contractors:	EnviroMine/Les Consultants SM

Objective:
The objective of this project is to monitor the Solbec Cupra tailings impoundment during (1995) and after flooding (post 1995). The monitoring program includes surface and ground water chemistry, hydrology, water balance (e.g. seepage, water depth), meteorological (e.g. precipitation), wave action (e.g. resuspension of particles), and microbiological activity.

Status:
Distinct from underwater disposal, wet barriers is defined as establishing a water cover on oxidized tailings. As with underwater disposal, further oxidation is considered unlikely but the mobilization of the soluble salts becomes a major consideration. This closure option may be attractive if the fate of these oxidation products can be predicted.

In order to commence flooding of the site Cambior completed the construction of two dams in 1994/95. Tailings from the higher elevations were moved to the lower areas and about 13,000 tonnes of limestone was added and mixed to the surface of the tailings impoundment to neutralize most of the accumulated acidity in the oxidized tailings. Several piezometers were installed in late 1994 and one sampling campaign was completed. Rehabilitation costs to 1995 for the 66 hectare Solbec Cupra tailings impoundment are estimated to be about $2.1m.

The 1995 monitoring program revealed a deficit in the water balance of about 2.6Mm^3. Porosity measurements versus tailings saturation, high degree of evaporation during the summer, seepage through the dams and into the underlying soils are possible reasons for the deficit. Conductivity and pH measurements on surface influent and effluent samples of the tailings pond were of acceptable quality. Ferrous iron measurements of surface pond waters ranged from 0 to 3ppm. Results from groundwater and pore water samples are erratic. A microbiological evaluation, consisting of 9 stations where tailings solids are sampled 3 times

a year is underway. The first campaign was completed in 1994 prior to flooding for comparison purposes. Most of the 1995 samples had a pH in the 6.5 range as a result of the limestone mixed in with the tailings. Some were found to be at or below 3.0. The results indicate that after one year of monitoring, the microbial aspects show an improvement in quality. The bacterial activities are reduced.

PREVENTION AND CONTROL Wet Barriers

Project 2.15.1a: A Study on Water Covers for the Decommissioning of Mine Waste Disposal Sites - Noranda Technology Centre

Budget: $487,000 (a,b)

Sponsor: Noranda Technology Centre (NTC) $253,000

Expenditures: $253,000

Manager: R. Michelutti, Falconbridge

Contractor: Noranda Technology Centre

Objective:

The project, conducted jointly by NTC and CANMET (2.15.1b), is using laboratory, numerical, and field methods on oxidized tailings to obtain the key parameters for evaluating the effect of different depths of water cover on the long term quality of the surface and interstitial water. NTC is studying the diffusion coefficients and fluxes, and has completed field tests at the Mattabi tailings site.

Status:

Covering sulphitic tailings with water effectively reduces oxygen influx to the tailings and the resulting acid generation. However, metals present in porewater solutions or in soluble mineral phases may still be released from the flooded tailings site. Results from a column experiment where oxidized tailings are covered by 1m of water showed that transfer of zinc, sulphate, and iron from the tailings to the water column could occur, inducing reactions with decreasing pH. These upward fluxes are influenced by hydrogeological conditions within the tailings and by the chemistry of iron minerals. The upward metal fluxes can last for long times, but decrease with time. Uncontrolled metal fluxes may signify the need to treat the water before releasing to the environment. The upward fluxes can be limited with the addition of a protective sand layer over the tailings. The sand and iron minerals act as a precipitation-sorption layer to impede metal transfer. Seepage quality from oxidized tailings under water cover is controlled by dissolution of soluble minerals present in the tailings prior to the placement of the cover. The quality of the seepage can be initially very poor, but improves as the minerals dissolve and become depleted. Analysis of column effluent after 4 pore volumes showed rapidly decreasing zinc concentrations, while sulphate concentrations remained high. Results from the Mattabi tailings case study suggest that removal of zinc by treatment of surface and seepage water would be required for a long period after implementation of the water cover. It is recommended that further work be carried out on the geochemical processes which influence metal releases (2.15.2), and on methods to enhance the chemical stability of metals under the water cover.

The costs for containment structures for an adequate water storage over the tailings are always high. It is recommended, before deciding to commit to these costs, to evaluate treatment and maintenance requirements using laboratory and field testing. Models (e.g. WATAIL) to investigate the effect of establishing a water cover at various times in the

depositional history of an impoundment do exist. The Mattabi test case was used to demonstrate the importance of early application of the water cover.

PREVENTION AND CONTROL Wet Barriers

Project 2.15.1b: A Study on Water Covers for the Decommissioning of Mine Waste Disposal Sites - CANMET

Budget: $487,000 (a,b)

Sponsors:

INCO $85,000

Lac Minerals $15,000

Ontario $30,000

Expenditures: $130,000 (b)

Manager: R. Michelutti, Falconbridge

Contractor: CANMET

Objective:

The project, conducted jointly by NTC (2.15.1a) and CANMET, is using laboratory, numerical, and field methods on oxidized tailings to obtain the parameters necessary for evaluating the effect of different depths of water cover on the long-term quality of the overlying and interstitial water. CANMET is studying the oxygen diffusion, sediment erosion and metal release characteristics of underwater deposited tailings and waste rock in laboratory column experiments.

Status:

Separate experimental columns (0.3m x 0.3m x 2m high clear acrylic) are set-up for partially oxidized and weathered waste rock, partially oxidized and weathered tailings (as deposited and unclassified), unoxidized fresh tailings (unclassified), unoxidized fine tailings and unoxidized pyrrhotite tailings. In another experimental set-up, the reactive tailings are covered at the interface with an additional layer of desulphurized tailings or an organic layer.

Oxygen diffusion experiments have shown that dissolved oxygen in the interstitial water is rapidly depleted in the waste material within the first 10cm of surface irrespective of its nature, limited only by the low oxygen diffusion and solubility in water. It is further observed that oxygen diffusion is a rate limiting step for sulphide oxidation underwater. In the metal flux studies, it is noted that surface oxidation of the waste material is occurring at the interface in all columns except for those where an additional layer covered the waste.

The most promising results have been for columns containing an organic cover layer over the waste. Here, the organic matter not only consumed oxygen but produced ammonia alkalinity and reducing conditions within the waste material which prevented upward migration of contaminants from previously weathered and oxidized waste. The resultant alkalinity increased the pH to about 8 in the upper lying water column at the same time neutralizing the free acid as it migrated upwards from the oxidized waste below the organic

cover. Studies on wind and wave induced erosion have also been completed. The non-cohesive till fraction of the tailings is most susceptible to erosion.

PREVENTION AND CONTROL Wet Barriers

Project 2.15.2:	Metal Releases after Flooding
Budget:	$200,000
Sponsor:	To be determined
Manager:	To be determined
Contractor:	To be determined

Objectives:
The objectives of the project are to evaluate and characterize the short, medium and long term metal release rates to surface water and through seepage follow flooding of a full scale tailings site.

Status:
Covering sulphitic mine tailings with water effectively reduces oxygen influx to the tailings and the resulting acid generation. However, metals present in porewater solutions or in soluble mineral phases may still be released from the flooded tailings impoundment. Results from a column experiment where oxidized tailings are covered by 1 m of water showed that transfer of zinc, sulphate, and iron from the tailings to the water column could occur. The transfer could be controlled by the addition of a diffusion layer (organic or non-organic materials) over the tailings.

Metal types, concentration and loadings, as well as variations with time, have to be known to confidently evaluate the costs and benefits of using a water cover for decommissioning of oxidized tailings. For maximum environmental benefit, water covers should be applied as early as possible after deposition. An excellent site to perform a field evaluation to evaluate metal release rates is Solbec Cupra where flooding has just reached the elevation where water is flowing over the control structure.

Monitoring of the site has begun in a separate project (2.13.2d). Additional monitoring was recommended following detailed laboratory studies (2.15.1a). These incluse a detailed water balance for the site and long term hydrological and geochemical processes. Kinetic testing of various tailings materials to establish a geochemical comparison base for operators who are contemplating flooding for close-out was also recommended. Discussions are underway on the preparation of a detailed scope of work. The project should begin in the summer of 1996.

Project 2.21.3a: Peer Review of Waite Amulet and Heath Steele Soil Covers
Budget: $50,000
Sponsor: ..... Cominco $47,000
Expenditures: $40,000
Manager: R. Gardiner, Cominco
Contractor: University of Saskatchewan

Objective:
The objective of this project is to complete a scientific review of the design and evaluation of engineered natural soil covers at a number of sites, including Waite Amulet and Heath Steele.

Status:
Soil covers appear to be an effective engineered solution for the management of acidic drainage. In recent years, there has been more interest in several parts of the world towards developing a better understanding of the long term behaviour of soil covers and the performance appears to be encouraging. The study reviews important case studies from several regions of the world. In particular the Heath Steele and Waite Amulet projects can be cited as two good examples.

The primary stage in design of a soil composite soil cover is the hydraulic characterization (moisture movement) of the soil cover structure. Several other phenomenon like transpiration (plant), freezing and thawing, weathering and erosion also influence the performance of soil covers. The current understanding of the performance of soil covers with respect to design and construction procedures can be used to develop further improvements and to come up with alternative design and construction procedures which are economical. Based on the present state-of-the-art practices the following parameters were identified to be the key requirements towards achieving a better soil cover: design (low k, high saturation); soil materials used; monitoring (proper instrumentation); performance (short/long term); effect of weathering and erosion; and economics.

The studies conducted for this report were useful in providing some recommendations for possible future soil cover research. There is a need to develope devices which can reliably predict the suction measurements in the soil covers. This is one of the key measurements from which the performance of the soil cover can be estimated. More rigorous flow models based on rational approaches taking into account several influences such as weathering (i.e. infiltration-evapotranspiration, freezing-thawing, vegetation and erosional aspects) are necessary for both the laboratory and field levels on a long term basis. Case histories on the performance of soil covers in various parts of the world would be helpful in understanding

aspects related to soil covers. Full scale models using varying degrees of conservativeness would be useful to come up with economical designs and for developing rational approaches for soil covers.

Project 2.21.3b: Peer Review on Covers made with Non-Traditional and Synthetic Materials

Budget: $20,000

Sponsors: .....Manitoba $10,000

CANMET..... $10,000

Expenditures: $10,000

Manager: B. Price, MEI

Contractor: University of Saskatchewan

Objective:

The objective of this project is to complete a literature review and an assessment of non-traditional soil and synthetic cover materials for potential use in acid mine drainage cover applications.

Status:

The objective of 2.21.3a was to conduct a review of processes and methods for soil covers. It also included a critical review of the Waite Amulet and Heath Steele sites. In addition it involved identifying other aspects of dry covers and providing recommendations for future research. While the tasks described in the work attempted to thoroughly encompass the dry cover area, this work did not attempt to address the many non-soil based covers gaining prominence. Some of these, such as geosynthetic clay liners (GCL's), polymerized bentonite modified sand, polypropylene fibre reinforced soil and concrete, asphalt emulsion etc., have shown considerable promise and may offer needed solutions in the design of acid mine drainage covers.

A literature review and the preparation of a database on alternate cover materials is underway. Properties such as strength, flexibility, permeability, durability and the physical, chemical and biological processes which alter their performance with time will be included. This database will include test sites or case histories illustrating the use of these materials and is organized according to material (i.e. asphalt barriers, shotcrete, fibre reinforced grouts and concrete; fly ash mixtures; tailings as cover materials; bentonite mixtures; geosynthetics; geosynthetic clay liners; organic, peat and sludges for covers; wax and/or jet grouting; and miscellaneous).

The properties of these materials, a description of their application and a review of their performance is underway. This review and examination would be combined with a discussion of their potential for use in acid mine drainage cover applications and requirements for future research in this area.

PREVENTION AND CONTROL Dry Barriers

Project 2.22.2b:	Evaluation of Dry Covers Built from Mine Tailings - Field
Budget:	$200,000 ($412,150 Associate Status)
Sponsors:	..... Québec $66,667
	Itec Minéral inc. $66,666
	CANMET $66,667
Expenditures:	$30,000
Manager:	L. Bienvenu, Ministère des Ressources naturelles (MRN) du Québec
Contractor:	École Polytechnique

Objective:
The objective of this study is to develop an alternative approach to cover design by using tailings in multilayer systems. The specific objectives are to study the performance of various cover configurations, on a large scale, to evaluate the actual behaviour of such systems exposed to realistic conditions, and to establish an optimum design procedures based on technical and financial aspects. The laboratory portion will result in a rational design process that could be used at different locations when only basic information (e.g. grain size, mineralogy) are known.

Status:
The objectives of the first phase (2.22.2a), which were to establish the calculation bases from laboratory experiments and numerical calculations, have shown that a capillary barrier can be created from non-reactive tailings. This layered system is effective to reduce the infiltration of water and to limit the diffusion of oxygen to a low enough level, thus preventing the generation of AMD from the sulphide materials underneath the cover.

Six experimental cells have been constructed on a site near Val d'Or, Québec. Five of the cells include a three-layer cover made of sand with tailings or silts, while the last cell serves as a reference test plot. Each cell is instrumented to establish hydrologic conditions in and around the controlled volume. Instruments installed include TDR probes to measure water content in each layer, transducers to evaluate water pressure (suction), thermal sensors for temperature, and lysimeters that capture underground water to monitor the evolution of the leachate quality over time. A meteorological station has also been installed on the experimental site to provide weather conditions to properly evaluate the water balance.

The project also includes laboratory experiments to characterize the different material, and to establish design procedures from physical and numerical models. Furthermore, a cost analysis will be conducted to allow an economic evaluation of various cover design alternatives. Preliminary results are very encouraging, and tend to confirm the data gathered from laboratory experiments.

Project 2.23.2c: A Tracer Study of Fluid and Contaminant Movement in the Upper Surface of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines

Budget: $78,200

Sponsors:
Falconbridge $39,100
Ontario $20,000
CANMET $20,000

Expenditures: $70,000

Manager: B. Swarbrick, Falconbridge Limited

Contractors: E.I. Robinski Associates Ltd./University of Saskatchewan

Objectives:

The objectives of this study are to verify modelling results of the behaviour of thickened tailings disposal against field observations. Specific objectives include determining the net infiltration due to climatic flux, the pathway and rate of infiltrating water and the role played by the zone of capillary saturation in the attenuation of infiltration and contaminant migration.

Status:

One hundred and thirty-five mini-piezometers were installed at three test sites on the tailings deposit in late 1992. The three sites were located downslope and at increasing distance away from the top of the cone. Two salts were chosen as a chemical tracer, potassium bromide and potassium iodide, which have high solubilities and are not originally present in the tailings. The presence of the anions in samples would be indicative of contaminant migration through the system. The system was subsequently "seeded" during the fall of 1992 and sampling campaigns were completed in 1993, 1994 and 1995.

The hydrogeology of the cone was studied (2.23.2ab) and it was predicted that average pore water velocities were quite low, ranging from 0.1cm/yr to 69cm/yr which would allow for low contaminant migration rates. The first set of results had higher than predicted velocities but subsequent sampling showed that the relative rates were actually slower and in the predicted range.

In early 1995, the tracers were not detected in the samples recovered from the mini-piezometers. Dilution was found to be the problem. Core samples, in addition to regular monitoring, was completed in September 1995. With lower detection limits possible for the analyses of the core samples, the chemical tracer potassium iodide was detected.

Kidd Creek is proposing additional cores (9 in total) at strategic locations between the three test sites in 1996. The results will be used to calibrate models on the performance of the TTD method with respect to seepage and contaminant transport. The final report will be submitted in late 1996.

Project 2.23.3b: Design Parameters - Pervious Envelope and Porous Surround Methods
Budget: $25,000
Sponsor(s): To be determined
Manager: To be determined
Contractor: To be determined

Objective:
The objective of this project is to evaluate the design parameters and basic principles needed to obtain a pervious envelope/porous surround effect. Both the natural porous surround (Falconbridge) an the engineered pervious envelope (Saskatchewan sites) methods will be analysed and key variables and requirements identified.

Status:
The porous surround/pervious envelope concepts are based on the fact that ground water flow into low permeable tailings masses can be minimized if high permeable soils are placed adjacent to and surrounding the tailings. If differences between soil and tailings are sufficient, ground water penetration into the tailings mass will be eliminated or reduced to acceptable levels. Leaching of the tailings is then theoretically reduced to acceptable levels, creating a permanent, cost effective, maintenance free tailings abandonment strategy. An impermeable cover may or may not be required to further reduce surface water penetration and subsequent oxidation in the unsaturated zone.

A MEND study (2.23.3) completed in 1994 has concluded that, based on field activities and computer flow modelling conducted over the past three years, conditions for porous envelope containment are occurring at the Falconbridge Fault Lake tailings site. The engineered multilayer envelope system referred to as the "Pervious Surround Method" is being used at Rabbit Lake in northern Saskatchewan. The concept is being refined for new tailings disposal proposals for the McClean and the Key Lake sites.

The MEND Secretariat has learned that a document reviewing the pervious envelope concept is in preparation by Cogema. The information will supplement the Environmental Impact Statement submitted by the company in late 1995. As a result, it is suggested that the project be delayed until proper review of the document is completed by members of the Prevention and Control committee. The report is reviewing the concept of the pervious surround method, its applicability to Saskatchewan sites and to Cogema's Cigar Lake site. Although conceived for use as a disposal method for uranium mill tailings, the concept is however considered to have potential applications for other wastes.

PREVENTION AND CONTROL Dry Barriers

Project 2.25.3: Assessment of Covers for Reducing Acid Generation from the Strathcona Tailings

Budget: $280,000 ($204,000 Associate Status)

Sponsors:

Falconbridge	$140,000
Ontario	$70,000
CANMET	$70,000

Expenditures: $370,146

Manager: G. Hall, Falconbridge

Contractors: Lakefield Research/Falconbridge

Objective:

The main objective of this one-year pilot test program is to comparatively evaluate the effectiveness of various organic cover materials (e.g. peat, municipal solid waste compost and lime-stabilized sewage sludge (LSSS)) at limiting or reducing the impacts of acid generation on the environment from acid generating tailings. An inorganic cover material (desulphurized tailings) was also included in the study, both for comparative purposes and due to the economic availability of large volumes of this material at operating mining properties.

Status:

The properties of a good cover material include the inhibition of oxygen infiltration and the limitation of influent precipitation into the underlying reactive tailings. The results to date from the pilot scale test cells show that, of all the materials tested, the LSSS performed best. It demonstrated high oxygen consumption ability, maintained a relatively constant moisture content throughout its depth, had a low surface evaporative flux, and maintained a relatively low rate of evaporative loss even under drought conditions. Underlying oxidized tailings pore waters have shown an increase in pH and a black band (i.e. metal sulphide precipitate) has formed at the tailings-cover interface since monitoring began.

The desulphurized tailings had a high air entry value, low hydraulic conductivity, and low salt migrations which are considered favourable cover characteristics. However, due to the evaporative losses and resultant formation of cracks that permitted oxygen to migrate to the underlying tailings, desulphurized tailings are considered unsuitable as a single cover layer. The application of a granular cover over the desulphurized tailings material has effectively limited the evaporative loss from the cover. The effects of this on the overall behaviour of the material as a cover have yet to be evaluated. The compost material demonstrated high oxygen consumption abilities and was found to be very resistant to evaporative loss and salt migration. Compost overlying fresh pyrrhotite tailings has prevented oxidation. However, compost overlying oxidized tailings has shown no net positive impacts. Peat appears to show

the least favourable cover characteristics of all the organic cover materials tested. It did not have any effect on oxygen migration and exhibited high evaporation rates.

PREVENTION AND CONTROL Waste Rock

Project 2.31.1c: Additional Monitoring of the Composite Cover at Heath Steele
Budget: $50,000
Sponsors: Noranda - BM&S (Heath Steele) $29,000
CANMET $25,000
Expenditures: $25,000
Manager: M. Patterson, Heath Steele Mines
Contractors: Noranda Technology Centre/Heath Steele Mines

Objective:
The objective of the project is to continue to monitor the performance of the engineered soil cover placed over waste rock pile 7/12 for an additional two years. The performance of the cover will be assessed in reference to pile 18B, which does not have a soil cover.

Status:
This work will help assess the effectiveness of engineered soil covers for the reduction of AMD within oxidized, mine waste rock piles. Additionally, the continued monitoring of the water quality emanating from the pile will further define the role that these type of covers could play in mine site reclamation.

A program to monitor the composite cover and the uncovered pile was continued in 1995. In the uncovered reference pile 18B, pore gas oxygen and pile temperature were measured. Pile 7/12, covered with the engineered soil cover, was monitored for: pore gas oxygen, pile temperature and leachate quality and quantity. Monitoring of the cover itself consisted of measurements for: moisture content, hydraulic conductivity, soil suction, pore gas oxygen, and cover temperature. A meteorological station on top of pile 7/12 provided site weather conditions.

Preliminary results of the monitoring indicate that:

(1) The till core in the engineered cover remains at a high degree of saturation, effectively reducing oxygen ingress to the waste rock in pile 7/12. Pore gas concentrations within the pile were near zero, while those at reference pile 18B were near atmospheric levels.

(2) Leachate quality and loadings from pile 7/12 improved slightly in 1995, with the possible exception of copper. Leachate quality remains above typical effluent discharge criteria.

(3) Water infiltration through the engineered cover remained at 2% of normal precipitation. The hydraulic conductivity of the till core was measured as $1x10^{6}$cm/s.

PREVENTION AND CONTROL ***Waste Rock***

Project 2.36.2: Hydrogeochemistry of Oxidized Waste Rock and AMD Prediction Techniques

Budget: $128,000

Sponsors: .....Noranda $78,000

CANMET $50,000

Expenditures: $98,500

Manager: M. Patterson, Heath Steele Mines

Contractor: Noranda Technology Centre

Objectives:

The objectives of the study are to: investigate the immediate effects of dumping oxidized rock into fresh water; calculate the acidity inventory in the oxidized waste rock; evaluate the dissolution rates of different secondary minerals (i.e. oxidized products); assess factors controlling the release of contaminants (e.g. solubility control, dissolution rate control, and diffusion rate control); and investigate the contaminant transport phenomenon by unsaturated flow within oxidized waste rock.

Status:

The oxidized waste rock samples used in the dissolution tests were composites from sixteen trenched samples in roughly equal proportions, which is regarded as representative of the surface strata of the Stratmat dump. The dissolution experiment commenced in March 1995 and has lasted for over 250 days. It was conducted in duplicate using two plexiglass cylinders measuring 1.3m tall and 20cm in diameter. The work was conducted in three stages to:

- monitor water quality upon dumping the oxidized rock into fresh water;
- monitor water quality evolution while rinsing the oxidized rock with fresh water; and
- monitor water quality of a water cover installed after rinsing ceases.

In stage I, it was found that simply dumping the oxidized waste rock into fresh water caused significant quantities of soluble minerals to dissolve. The ease of dissolution of different metal sulphates was found to follow the sequence Al > Cu > Mg > Zn > Mn > Ca > Pb in the rinsing stage. The list is important and may have interesting applications. For example, if oxidized waste rocks are to be rinsed to remove contaminating oxidation products, particular attention should be given to Pb, Ca and Mn, since these metals are the most difficult to dissolve and therefore take the longest time to wash out. Various parameters, such as pH, Fe(total), Ca+Mg+Mn, were monitored during the static phase and compared to other results. It is interesting to note that, although the 60cm water cover was static, it was well mixed throughout, as indicated by the fact that the parameter values monitored at the top coincide with those at the interface. The pH of the water cover started declining

immediately after the installation of the water cover from about 4.5, to eventually stabilize at 3.5. The experiment reveals that, even after washing the waste rock with 72 pore volumes (18 cycles), the water quality still would not meet the regulations with respect to pH, Zn and Pb.

PREVENTION AND CONTROL Waste Rock

Project 2.36.3: Literature Review of Methods for Characterization of Waste Rock Prior to Underwater Disposal

Budget:	$30,000
Sponsor(s):	To be determined
Manager:	W. Price, B.C. MEI
Contractor:	To be determined

Objective:
The objectives of this project area; to review the possible means of materials characterization, to evaluate the cost/benefit, and to recommend laboratory and empirical test protocols for determining the impact on water quality resulting from the underwater disposal of oxidized waste rock.

Status:
Several methods are available to prevent the generation of acidic drainage from mine wastes. One method that is commonly used to prevent acidification is the placement of acid generating materials underwater. Covering the mine waste with water will minimize the transport of oxygen and therefore limit or even totally prevent acid generation. However, if the waste material has already oxidized, it may contain significant amounts of readily soluble deleterious substances that dissolve into the water cover making underwater disposal less attractive. From the early days of mining, there is a legacy of potentially acid generating waste rock in which significant oxidation has already taken place. For many of these wastes, underwater disposal is an attractive means for arresting the acid generation. However there is considerable uncertainty about the consequent effect of secondary mineral solubility on water quality.

Previous work to predict the acid rock drainage potential of a particular rock type is based on using fresh materials created by the mining operation. The project will review the prediction methods and determine their applicability to oxidized materials. The resulting recommendations will be of great assistance for existing and planned mine sites that may have oxidized materials on site and are considering other options for close out (e.g. moving to pit and flooding). A test protocol for predicting the impacts of moving the waste and placing it underwater will result. This protocol could be used by an existing operation contemplating the placement of oxidized materials underwater.

What is envisaged in this project is a literature review of prediction methods used to date and the development of a protocol for testing oxidized waste rock. The proposed protocol would then be tested in large scale pilot cells on several oxidized waste rock samples supplied by funders. The effectiveness of the recommended protocol would be evaluated and changes made, if necessary. The budget ($30k) will be expanded to include additional

samples of oxidized waste rock from funding companies. Discussions are currently underway on the development of a detailed work plan.

PREVENTION AND CONTROL Waste Rock

Project 2.37.1: Layering Different Types of Waste Rock to Create a Non-acid Generating Composite - Case Studies

Budget: $50,000

Sponsor: ..... CANMET $45,000

Expenditures: $0 (Contract signed late December 1995)

Manager: BC MEMPR

Contractor: Mehling Environmental Management

Objective:

The objective of this project is to complete an international case study review on the use of blending/layering as a close-out option for mines that contain both acid generating and non-acid generating waste rock. The general objective is to document the use and success (or failure) of blending/layering as a method for preventing acidic drainage and metal leaching.

Status:

As a long term means of preventing the onset of acidic drainage, potentially acid generating and non-acid generating waste rock can theoretically be blended or layered to produce an environmentally benign composite. The technique has been implemented, or proposed at many mine sites. Where the excess alkalinity is sufficiently large, the two materials can be combined to create a non-acid generating composite. This process requires detailed monitoring, separate materials handling and blending during waste disposal. Typically, blending is achieved by sequential deposition of the different materials in adjacent layers of experimentally defined proportions. The review will cover practical field experience and provide commentary on the implementation of this technique as a permanent prevention measures.

The case study review, which began in January will:

- Develop a template of data to be compiled for each case study;
- Select and rank appropriate case studies through discussion with experts in the field; and,
- Compile data on the selected case studies by:
  - a) conducting a literature search for published information.
  - b) soliciting previously compiled readily available documentation from the relevant mining company
  - c) working directly with the raw data at relevant mine sites, company offices, and/or research establishments.
  - d) interviewing company personnel and experts .

The final report will be in sufficient detail to enable the reader to compare the cited case studies and their effectiveness and difficulties, practical problems and solutions to their own mining project.

PREVENTION AND CONTROL Waste Rock

Project 2.37.2: Review of Methods for Delaying Onset of Acidic Drainage - Case Studies

Budget: $50,000

Sponsor: ..... CANMET $45,000

Expenditures: $5,000

Manager: W. Price, B.C. MEI

Contractor: Steffen, Robertson and Kirsten (Canada) Inc.

Objectives:

The objectives are to review methods to delay the onset of acidic drainage and metal discharge from mine rock, and in particular to compile international case histories from mine sites where temporary delay of acid generation has been assessed or attempted. Each case study will document the procedures and indicate the successes and failures.

Status:

Methods for delaying the onset of acidic drainage and metal discharge may be appropriate when long term control measures are anticipated, but cannot be implemented immediately, for example, when relocation of the waste rock to a pit is planned after cessation of mining. The review will comprise case histories from mine sites where temporary abatement techniques have been assessed or attempted.

The experience gained to date shows that any survey of measures dealing with short term storage of waste rock will need to include many that were initially considered permanent such as: bactericide application; phosphate application; commercial reaction inhibitors; and irrigation with alkali. It will also be necessary to consider measures that have been successfully applied as permanent but can be designed as delay techniques. Examples include: simple soil covers; shotcrete and cementitious covers; oxygen-consuming organic covers; inorganic oxygen-consuming covers, freezing; and lime application. Cost data is another important parameter that must be considered for the evaluation of delay methods.

The project was started in late December and is in the process of collecting relevant information. The materials, methods and reasons for decisions involved in each of the case studies, actual and proposed, would be useful information for operators contemplating a similar disposal technique as part of their waste management philosophy. The final report will be in sufficient detail to enable the reader to compare the cited case studies and their effectiveness and difficulties, practical problems and solutions to their own mining project. The intent of the final report is to allow operators to assess these interim options for site specific applicability prior to long term disposal.

Project 2.37.3: Characterization of Test Materials from Samatosum Column Study
Budget: $35,000
Sponsor: ..... CANMET
$22,120
Expenditures: $5,000
Manager: W. Price, B.C. MEI
Contractor: Morwijk Enterprises

Objectives:
The objectives of this study are to review and compile existing field and laboratory data, review interpretations and re-interpret data where necessary, estimate the long term success of layering, and recommend ways to improve and test layering at other mine sites.

Status:
Samatosum chose to layer potentially acid generating (PAG) and mafic pyroclastic; non-net acid generating (MAF) as distinct 6m lifts in the waste rock pile. The theoretical basis was that an overlying MAF layer would release net alkalinity into downward-seeping infiltration, neutralizing acidity within the PAG layer below. Then any net acidity migrating downwards from a PAG layer would be further neutralized by an underlying MAF layer.

As confirmation of the success of layering, five columns were constructed in a laboratory and water was continuously flushed through these columns for a maximum of about five years. At the end of the testwork, the layered columns had not generated net acidity. Furthermore, extrapolations of trends into the future indicated that the columns would never generate net acidity. Under field conditions, the full-size pile has shown that layering has been successful at maintaining pH-neutral to alkaline conditions in seepage to date.

A critical aspect in comparing laboratory-based testwork to in-field performance is a detailed evaluation of field data. For the Samatosum study, the two critical areas are details of pile construction and performance of the field pile based on monitoring data. Information collected from the column study will yield the critical information on the laboratory-scale performance of the waste rock. Some post-test analyses have been proposed and recently started on column residues. ABA and post-metal contents will be determined and compared to pre-test results. Secondary minerals accumulation in the column waste rock will also be carried out.

The project was started in November 1995. Based on the review of field-based and laboratory-based procedures and findings, recommendations will be made to improve the procedures and provide guidance to mines considering layering as a control technique for acidic drainage.

TREATMENT

Project 3.41.1a:	In Situ Treatment of AMD
Budget:	$41,000
Sponsors:	..... Falconbridge $11,000
	MOEE $30,000
Expenditures:	$41,000
Manager:	D. Abbott, MOEE
Contractor:	University of Waterloo

Objectives:
To develop and test the use of permeable reactive walls for the subsurface treatment of drainage waters derived from sulphide-bearing mine-tailings impoundments and to demonstrate the use of this technology on a pilot scale in the field.

Status:
The first year of this study (Phase I) dealt with the theoretical and laboratory assessment of reactive mixtures potentially suitable for treatment of drainage waters associated with inactive mines wastes. A variety of reactive materials were studied. Selection of an optimum material for field testing was made along with development of fundamental characteristics, porosity, and permeability required for solute-transport modelling.

A test cell was placed in a plume of tailings-derived groundwater at a nickel mine was able to reduce sulphate concentrations from 3500mg/l to 7mg/l, iron from 1000 to $<$5mg/l, and nickel from 2 to $<$0.01mg/l. Results indicated that 5 to 10 years of life can be expected from these permeable reactive walls.

Such a system may have an important role to play in treating contaminated water plumes at acid-generating waste sites.

Further results are expected from the field work in 1996.

TREATMENT

Project 3.41.2: Metal and Sulphide Surface Biomineralization
Budget: $20,000
Sponsor: Environment Canada $20,000
Expenditures: $20,000
Manager: Bill Blakeman, Environment Canada
Contractor: Waste Water Technology Centre

Objectives:
To develop a biomineralization process to biologically immobilize leachable and soluble metals in acid-generating waste rock and tailings.

Status:
Tests on the use of a biological system for the detoxification of cyanide waters from heap leaching have shown that soluble metal levels and sulphate oxidation rates were lowered. These observations led the proponent to propose that metal biomineralization could be used as an in-situ treatment option for acid-generating waste sites.

Such a system may have economic use in certain situations such as temporary prevention of acid generation in a waste rock pile, while the rock is being stored awaiting final disposal into a mined-out open pit.

The tests used native microorganisms from the Mine Doyon and Island Copper mines. Column tests will follow flask tests, which were followed by humidity cell and column tests.

Next Steps:
The results of the laboratory tests will be used to design field tests and to conduct a preliminary economic feasibility study. The proponent has made proposals to industrial sponsors for funding and testing of the sponsors materials; the project will not proceed further without this support.

TREATMENT

Project: 3.42.2 Lime Sludge Stabilization, Disposal and Use

Budget: $165,000

Sponsors: Canada-Brazil Cooperation Project $105,000

Expenditures: $45,000

Manager: T. Hynes

Contractor: CANMET

Objectives:

To evaluate and document methodology for the long term stabilization, disposal and potential beneficial use of lime treatment sludge.

Status:

Lime treatment is the principal method for treating acidic water for the foreseeable future, and this activity represents a large proportion of the liability of acid generating mine wastes. Although lime treatment technology is well developed, a good understanding of the best methods for sludge stabilization and disposal under a wide range of conditions is not well developed. The principal concerns about the treatment sludge are the volume occupied by the sludge and the chemical stability of the sludge, particularly with respect to heavy metals that have been coprecipitated with gypsum, and aluminum and iron hydroxides.

The review of lime sludge stabilization in project 3.32.1, Lime Treatment - Process Review and Sludge Stabilization, revealed that for most sites, the treatment products contained enough excess alkalinity to remain stable for a very long time.

Ten acid mine drainage treatment sites have been visited, samples collected, preserved and returned to the laboratory for evaluation.

The sludges are being physically and chemically characterized and will be subjected to washing and stability tests.

Future work, to be completed before the end of 1997, may include an examination of the disposal options for lime treatment sludges.

MONITORING

Project 4.5.4: Environmental Monitoring Handbook for Acid Mine Drainage
Budget: $65,000
Sponsors: CANMET $40,000
Ontario $40,000
Expenditures: $10,000
Manager: C. Weatherell, CANMET
Contractor: Terrestrial and Aquatic Environmental Managers

Objective:

The proposed MEND Environmental Monitoring Handbook will summarize all aspects of AMD that include monitoring and will provide a detailed reference of the techniques to be used in the field. The handbook shall describe techniques such as; geophysical monitoring, remote sensing, effluent monitoring, field evaluation techniques, biogeochemistry, etc., for the monitoring of waste water, mine tailings, waste rock piles, open pits and underground workings. The handbook will also address techniques recently developed (e.g., piezocone), currently being developed or on the frontier of modern monitoring technologies. Various techniques identified and described shall be ranked in terms of effectiveness for various mine waste scenarios, type of information, cost, etc. Recommendations as to the most useful techniques will also be made. These recommendations will be demonstrated by providing case histories for all techniques describing why the techniques were useful or in other instances why the techniques failed. For technologies not yet fully developed or employed, projections or recommendations as to the applicability of these techniques will be made.

The handbook will offer a practical guide containing proven technology to lead mining personnel, consultants, and government agencies to make informed decisions on the information gathering process as it relates to the mining industry.

Status:

A draft table of contents was completed and accepted. A draft copy of the manual is scheduled for completion May 31, 1996 and will be presented as part of Monitoring Workshop to be held in Saskatoon June 10, 1996. The final manual is scheduled for completion July 31, 1996.

MONITORING

Project 4.6.5b: **Laboratory Studies to Assess the Oxidation Potential of Waste Rock Representative of Pile Sized Material**

Budget: **$15,000**

Sponsor: ..... **INCO**

$16,925

Expenditures: **$16,925**

Manager: **M. McCann, INCO**

Contractor: **University of Waterloo**

Objective:

The primary objective of this work is to determine the reactivity of waste rock representative of material in the rock pile. The proposed approach involves the measurement of oxygen consumed by the rock in a closed cell. The oxygen uptakes rates are then compared with the rates of sulphate released after periodic rinsing of the rock samples. These oxygen consumption rates are representative of the actual oxidation rate of sulphide minerals and are independent of secondary reactions.

Status:

Reaction rates have been measured on numerous rock samples from the waste rock pile at Inco's Whistle mine and from Mine Doyon.

A draft final report is expected by May 31, 1996.

TECHNOLOGY TRANSFER

Project 5.4.2a:	MEND Handbook - Phase I
Budget:	$150,000
Sponsors:	..... CANMET
	..... $75,000
	Ontario $75,000
Expenditures:	$27,620
Manager:	G. Feasby
Contractor:	Norecol, Dames & Moore

Objective:
To provide, in a single set of updateable "stand alone" documents, a comprehensive summary of all the key information on the results of MEND investigations and related research on AMD. The document will be set of comprehensive working references for prediction, prevention, control, treatment and monitoring of acidic drainage.

Status:
One of the functions of the MEND program is to transfer MEND-developed technology to users and to ensure that the information is clearly understood, particularly for newly developed technology. In fact, poorly implemented technology could easily be very counter productive for MEND, and would result in lost opportunities to reduce the cost of dealing with acidic drainage.

The contractor has reviewed and summarized, all the reports, studies and results of the MEND program related to active treatment, passive treatment and monitoring. Working documents summarizing all the relevant information such as; application and limitations of the technology, long term implications and maintenance requirements as well as the financial aspects of implementing this technology have been prepared for these three sections.

The "Handbook on AMD Technology", due March 1997, will provide a comprehensive summary of all state-of-the-art AMD technology both through MEND and associate projects. The handbook will also provide information on engineering, economics, case studies and scientific data for mine and mill operators, engineering design and environmental staff, consulting engineers, universities and governments.

TECHNOLOGY TRANSFER

Project 5.6.3: Fourth International Conference on the Abatement of Acid Rock Drainage

Budget: $80,000

Sponsors: ..... CANMET $15,000

MAC $1,000

British Columbia $15,000

MEI $5,000

Managers: Mike Filion, Teck
George Poling, UBC
MEND Secretariat

Objective:
MEND will sponsor, and host the Fourth International Conference on Abatement of Acid Rock Drainage in Vancouver in June 1997.

Status:
The Fourth International Conference on the Abatement of Acid Rock Drainage coincides with the last year of the MEND program. Over the past few years, MEND and other research initiatives around the world have focused on the prediction, prevention and control, and long term management of acid generating tailings, waste rock and mine walls. These initiatives have sponsored the development of new technology that is being put in place under a wide variety of conditions.

An organizing committee has been formed and a professional conference organizer has been engaged to handle logistics and local organization.

The theme of this conference is **"Application of Technology"**, with technical sessions addressing basic research, case studies, control, monitoring and financial assurance. Short courses will be offered prior to the conference on several acid drainage related topics. Post conference technical tours and a trade show round out the conference program.

Five thousand copies of the second circular were distributed in English, French and Spanish with special emphasis being made to attract visitors from outside Canada. Roughly one quarter (25) of the papers to be presented will report on MEND projects. The conference is expected to attract over five hundred delegates.

TECHNOLOGY TRANSFER

Project 5.7.1: MEND Newsletter

Budget:	$20,000
Sponsors:	CANMET
	$4,500
Expenditures:	$4,500
Manager:	G. Feasby
Contractor:	In-House, MEND Secretariat

Objective:

To keep MEND Participants informed of progress on current efforts to find workable and economic solutions to the significant environmental liability posed by Acid Mine Drainage.

Status:

To ensure that the objectives of MEND are achieved, results of the research work on acidic drainage have to be transferred to users. Regular publication of a Newsletter is an effective way to inform MEND participants on research progress. It also promotes communication among members and advertises the existence and purpose of the MEND program.

Two issues have been published and distributed to over 600 people in 1993, and expanded to 900 addresses in 1994. Only one issue was published in 1995. Information was given on technical projects in the area of Prevention & Control and Monitoring, people involved in the Program, recent publications, upcoming events, and special features on how MEND operates. Future issues of the Newsletter will address the question of water covers, workshop summaries and updates on the international AMD community.

The Newsletter will continue to be published until December 1997 and the distribution will be expanded (other than by mail) through the MEND home page.

TECHNOLOGY TRANSFER

Project 5.9: Review of MEND
Budget: $80,000
Sponsors:
CANMET $40,000
Environment Canada $17,000
Cambior $2,000
Noranda $5,000
Barrick $5,000
Falconbridge $5,000
Teck $5,000
Quebec $10,000
New Brunswick $2,000
Placer Dome $2,000
Expenditures: $40,000
Manager: G. Feasby
Contractor: Young & Wiltshire

Objective:
The objective of this project is to conduct a review of MEND achievements versus objectives and to report the results of this review to the MEND Board of Directors.

Status:
The contractor is in the process of conducting interviews with representatives of MEND participants and potentially interested users of the MEND results outside the program. The contractor is examining the following issues:

- Success: What has the program achieved in relation to its objectives and expected impacts? How has the design and delivery of the program contributed to the success realized?
- Relevance: Do the program objectives and program design continue to be relevant in view of the success achieved, and in consideration of current environmental factors? Is there likely to be unfinished business when the program terminates?
- Alternatives: Could the program objectives be achieved at lower costs? Are there better ways of designing and delivering the program?

The approach being followed is:

- Review of MEND documentation;
- Interviews with MEND participants and associates;
- Surveys of mining companies and industry associations;
- Obtain expert opinion from professors, researchers and consulting firms.

The review will be completed in June, 1996.

PREDICTION ***Waste Rock Modelling (associate)***

Project Title: **Metal Transport and Immobilization at Mine Tailings Impoundments**
Budget: **$86,720**
Sponsors:
CANMET.....$20,860
Ontario.....$20,860
Ministry of Environment.....$45,000
Expenditures: **$56,240**
Contractor: **University of Waterloo**

Objective:
The objective of the research program is to develop improved techniques for predicting environmental effects of inactive mine wastes. Specifically, an existing numerical model will be enhanced and used to describe natural and induced attenuation mechanisms affecting the fate of dissolved metals down-gradient of mine tailing impoundments. The final model will be useful in the planning and implementation of reliable and economical long-term management and closure options for mine tailing sites.

Status:
Mathematical modelling techniques can be used to investigate the geochemical evolution and reactive transport of acid, metals and other components leached from tailings deposits. A new numerical transport model (MINTOX), developed at the Waterloo Centre for Groundwater Research (WCGR), is being used to simulate the geochemical behaviour of tailings impoundments, including the kinetic oxidation of sulphide minerals, acid generation, and transport of dissolved-phase components such as Fe(II), SO_4, and Al. Heavy metals mobilized under acidic conditions in mine tailings impoundments pose a potential serious risk to groundwater and surface water resources. Immobilization of these metals due to geochemical buffering in carbonate aquifers, can however, reduce this risk. An interim report describing the incorporation of the kinetic sulphide oxidation reactions into the prototype MINTOX model, and calibration to the Nickel Rim site has been completed. A preliminary sensitivity analysis has also been documented showing the importance of background concentrations of buffering minerals. In particular, plume behaviour has been significantly affected by variable oxygen diffusion rates within the unsaturated tailings zone, and with changing background dolomite/calcite concentrations. The final deliverables include a comprehensive report covering the close-out scenarios and sensitivity analysis, with applications to generic case-studies. A working computer program and example data sets will also be provided (October 31, 1996).

PREVENTION AND CONTROL Subaqueous Disposal (associate)

Project Title:	Subaqueous Disposal - Moose Lake (Falconbridge)
Budget:	$320,000
Sponsors:	
Falconbridge	$240,000
Ontario	$40,000
CANMET	$40,000
Expenditures:	$141,087
Manager:	G. Hall, Falconbridge
Contractors:	Lakefield Research/Rescan/University of Waterloo

Objective:
The objective is to determine the feasibility of depositing Strathcona Mill (SM) sulphide tailings into a low pH lake (Moose Lake) as a viable method of acid generation control.

Status:
The majority of the Falconbridge mining and milling operations in the Sudbury area are in the Moose Lake or Fecunis watersheds. Moose Lake covers an area of about ≈200 hectares with a maximum depth of ≈55m. Moose Lake was previously unstudied and may provide a unique location for the disposal of tailings which are potentially acid generating.

The study program included an environmental characterization of Moose Lake, characterization of the tailings, and a laboratory test program. The impact of mining activities is evident in the water chemistry and surface sediments of Moose Lake. Upper Moose Lake water is very acidic (pH < 3), very conductive (2270μmhos/cm), and contains elevated concentrations of sulphates, iron and nickel. A shallow thermocline was found which effectively isolates the bottom layer from the introduction of oxygen. The treated lower Moose Lake process water is slightly alkaline (pH 7.4), low in iron and nickel concentrations.

The laboratory test program consists of five subaqueous testing columns filled with different types of tailings (SM tailings, thickened SM tailings, pyrrhotite tailings, thickened pyrrhotite tailings, and pyrrhotite tailings with 100mm Moose Lake substrate) submerged under 1000 mm of the upper Moose Lake water. Insitu measurements were recorded for Eh, conductivity and temperature on a two-week interval. Pore waters were collected from the water cover, the interface and the tailings layer on a two-month interval, and analysed for metal and sulphate concentrations and pH.

After 10 months of monitoring and testing, the SM tailings showed the lowest impact on the overlying water cover followed by the pyrrhotite tailings with the substrate cover. With the exception of an increase in thiosulphate concentrations, the subaqueous deposition of thickened pyrrhotite tailings also had a minor impact on the overlying water cover. The

results of the column tests provide a model of the worst case impacts expected on the upper Moose Lake if fresh tailings are deposited above the chemocline and thermocline in shallow, acidic waters.

PREVENTION AND CONTROL Disposal Technology (associate)

Project Title: Separation of Sulphides from Mill Tailings - Field

Budget:	$110,000
Sponsors:	
INCO	$55,000
CANMET	$55,000
Expenditures:	$80,000
Manager:	R. Stuparyk, INCO
Contractors:	University of Waterloo/INCO

Objective:
The objective is to evaluate the potential benefits for the prevention of acidic drainage through the production of low sulphur tailings using a simple flotation procedure to reduce or eliminate the net acid generation potential by removing the residual sulphides into a flotation concentrate. This would allow the low sulphur tailings to be safely deposited in areas where contact with air and water are inevitable while the concentrate would be directed to a submerged storage area.

Status:
Three 10m x 15m field test pits were constructed at INCO's tailings area in 1993. These pits were lined with a 1.1mm thick polyethylene liner, isolating the contents from the surrounding groundwater flow system. Infiltration through the lysimeter is collected via a bottom drain. They were each filled with two-hundred ton bulk samples of low sulphur tailings (0.35%S), standard tailings (0.98%S), and mill total tailings (2.30%S) for long term acid and metal seepage evaluation. A detailed three-year monitoring program was established in 1993. This program included collection and analysis of the lysimeters effluent water, detailed monitoring of pore gas and porewater composition on a semi-annual basis, and determination of the solid-phase composition of the contents of the lysimeters.

The environmental benefits of the production of low-sulphur tailings were evaluated through a staged research program including static laboratory tests or acid-base accounting, column oxidation experiments and large-scale field lysimeters testing. From the laboratory component, the total tailings are potentially acid-generating, the main tailings fall on the border between potentially acid generating and the zone of uncertainty, and the low-sulphur tailings fall within the zone of uncertainty. It is not possible from these tests to state definitely that the low-sulphur tailings will not generate acidic drainage.

Results of the pore gas and porewater sampling of the field lysimeters show that the low-sulphur tailings are oxidized at a greatly reduced rate compared to the main and total tailings. Preliminary observations suggest that the environmental effects of the low-sulphur tailings will be less severe than those of the main tailings presently produced at the mill or the total tailings produced in the past.

Appendix E

Recommended Projects

Number	Titles
1.15.3	Prediction of Water Quality in Partially Flooded Pits Containing Waste Rock
1.16.2b	Additional Certified Reference Materials
1.19.3	Acid Rock Drainage Prediction Laboratory Project
1.28.1a	Understanding Physical Mechanisms in AMD Waste Rock Piles - Phase I
1.28.1b	Understanding Physical Mechanisms in AMD Waste Rock Piles - Phase II
1.41.5	Guidelines for Characterisation of Waste Rock Piles
1.62.1	Freeze Control of Tailings - Site Characterization and Sampling
1.62.2	Freeze Control of Tailings - Low Temperature Acid Drainage Laboratory Testing
2.15.3	Laboratory Investigation on Oxidation from Resuspension in Water Covers
2.18.1	Review and Documentation of Water Cover Applications
2.21.4	Protocols in Engineered Soil Covers Over Tailings and Waste Rock
2.22.3	Technical and Economic Feasbility of Using Desulphurized Tailings for Covers
2.22.4	Composite Cover Using Tainlings - Full Scale Site Monitoring
2.25.3	Assessment of Covers for Reducing Acid Generation from the Strathcona
2.25.4	Effectiveness of Paper Mill Sludges as Covers - Laboratory
2.30.1	Waste Rock Prevention and Control Guidelines
3.42.3	Disposal of Lime Treatment Sludge
5.1.2	Workshops
5.7.2	CD Rom Publications
5.8.1	Education Initiative

PREDICTION

Project 1.15.3*: Prediction of Water Quality in Partially Flooded Pits Containing Waste Rock

Budget: $30,000
Sponsor(s): To be determined
Manager: To be determined
Contractor: To be determined

Objectives:
The objectives of this project are to:

- Update the computer code of the current model of MINEWALL to a Windows programming environment (Visual Basic 4.0);
- Incorprate drainage inputs from associated tailings or waste rock;
- Limnological stratification and turnover;
- Equilibrium chemistry; and
- Formation and settling of mineralogical precipitants.

Fit With Program:
At a mine site, acid drainage and metal leaching results from many forms of rock exposure, including waste rock piles and mine walls. A common practice during mine decommissioning is the placement of sulphide-rich, potentially metal leaching waste rock and tailings into the open pit. The pit fills with water and the water cover prevents sulphide oxidation. In some cases, the final water level is insufficient to completely cover the waste rock, to levels that assure protection of the environmental quality, as with an impervious cover. An ability to predict the resulting water chemistry is seen as beneficial to assist operators to design various waste management scenarios involving open pits.

A previous MEND project (1.51.2) developed a computer program called MINEWALL 2.0. This program can be used to predict the evolution of drainage chemistry in open pits filled with water and has been successfully applied at several mine sites. In its present form, MINEWALL has several limitations that restrict its value to mine operators and regulatory bodies.

This project is designed to remove those limitations and expand the capabilities of MINEWALL to simulate other waste management scenarios involving open pits.

Projected Output:

A useful tool to assist operators and regulators to predict the quality of water in flooded open pits incorporating either waste rock or tailings waste material. These predictions can be used to development of waste management scenarios to optimize potential cover designs and to determine security and treatment requirements.

* *Requires Management Committee approval.*

PREDICTION

Project 1.16.2b*: Additional Certified Reference Materials
Budget: $150,000
Sponsor(s): To be determined
Manager: To be determined
Contractor: CANMET

Objectives:
To develop three additional reference materials covering a range of waste rock mineralogies and net neutralization potentials.

Fit With Program:
There are a variety of static tests that have been documented (1.16.1bc) and are used to predict the potential for acid generation or neutralization of mine waste material. However, no single method will predict, with confidence, NP values for all varieties of rock types. To increase the reliability and lend a sense of quality control to static test methods, tracability to a certified reference material or materials is necessary.

Approximately three static test methods will be selected for the certification program. An interlaboratory measurement program will be conducted for NP, NNP and other significant parameters for ARD static prediction techniques. Analysis for a minimum of total sulphur, sulphate, acid generating potential, and net neutralization potential (NNP) will be requested from participating laboratories. Approximately 20 laboratories will be sought to participate under arrangements similar to other CCRMP analyses programs. The results from the program (NNP, total sulphur etc.) will be statistically analyzed and an evaluation of the methods used will be performed.

Projected Output:
A report will be prepared containing all results for the ARD static prediction tests, statistical analysis of all results, method summaries and conclusions. The report, or a summary thereof, and a Certificate of Analysis will be provided with each bottle of standard prepared.

* *Requires Management Committee approval.*

PREDICTION

Project 1.19.3*: Acid Rock Drainage Prediction-Laboratory Project
Budget: $54,670
Sponsors: Environment Canada $6,850
Cominco $47,820
Manager: B. Godin, Env. Canada
Contractor: Synergetic Technology

Objectives:
The main objective of this project is to justify and design new laboratory tests that would be compatible with the requirements of predictive geochemical and physico-chemical models.

Fit With Program:
The existing standard laboratory tests for waste rock samples do not provide sufficient information necessary for reliable prediction of the environmental impact of acid rock drainage. Acid-base accounting tests and leaching tests do not address the thermokinetic and physical aspects of acid rock drainage. The proposed thermokinetic laboratory tests should provide information about oxygen consumption rates, effective order of sulphide oxidation reactions with respect to oxygen partial pressure, temperature dependence of acid generation and neutralization rates. This new information would allow one to verify the hypothesis about a thermodynamic catastrophe identified in a previous MEND project (1.19.2). This project theorises that certain values of a scaling parameter will lead to enhanced rates of acid rock drainage production.

Projected Output:
The most significant output would be laboratory test protocols that would yield considerably more information than present kinetic laboratory test methodologies. This information could be used for geochemical and physico-chemical modelling and to assist with understanding basic mechanisms controlling the generation of acidic drainage in waste rock. Validation of thermodynamic catastrophes for specific values of scaling parameters could also be verified.

* *Requires Management Committee approval.*

Project 1.28.1a: Understanding Physical Mechanisms in AMD Waste Rock Piles - Phase I
Budget: $45,000
Sponsor: Environment Canada
$40,000
Manager: B. Godin, Env. Canada
Contractor: Synergetic Technology

Objectives:
The objective of phase I of this project are simply to determine the controlling factor or factors which lead to steady state versus limit cycle or chaotic behaviour in predicting acid mine drainage generation in waste rock piles.

Fit With Program:
The management of acid rock drainage can be approached in two ways: by advanced planning and preventative management of the problems at an early stage of mine project development or by control and treatment of the problem once it has arisen. Accurate prediction may be based on an analysis of quantitative data from experiments and physico-chemical models, and potentially offers the most cost-effective means of reducing the environmental impact of AMD.

A nonlinear approach to modelling has been used for the chemical prediction of pyrite oxidation. Previous work (1.51.1, 1.51.2) indicated that in spite of the highly nonlinear kinetics of pyrite oxidation, chemical chaos does not develop in the AMD reactions. Strictly speaking the chemical interactions between the reactants lead to steady states and therefore predictable answers to the various input can be determined. However, project 1.51.1 showed on a qualitative basis that lag transport of reactants and reaction products lead to non-trivial behaviors. Another project (1.19.2) on the scaling effect of test sites, showed that pile size threshold leads to different temperature regimes. Understanding of the interactions of physical and chemical processes is essential for modelling of water quality in ARD waste rock piles.

Projected Output:
Quantitative results on the analysis of micro-scale, meso-scale and macro-scale characteristics of waste rock piles and the relative significance of interrelated physical and chemical factors responsible for acid mine drainage. A formulated, nonlinear reaction-convection-diffusion-infiltration-evaporation model involving coupled chemical and physical processes.

PREDICTION

Project 1. 28.1b: Understanding Physical Mechanisms in AMD Waste Rock Piles - Phase II

Budget: $54,200

Sponsor: ..... AECB $35,000

Manager: B. Godin, Env. Canada

Contractor: Synergetic Technology

Objectives:

The objective of the phase II of this project are to provide, limited in scope to non-biological factors, but realistic at high pH values, a user-friendly model which after including bacterial processes could become part of an expert system, useful as a predictive tool in the decision making process.

Fit With Program:

A primary goal of the Prediction program was to develop a comprehensive waste rock model for determining the acid generating characteristics of waste rock piles. The complex nature of the physical and chemical regimes interacting to produce acid rock drainage have forbade the development of such a model using conventional, linear, modelling strategies. However, previous MEND sponsored research (1.51.1, 1.51.2, 1.19.2) has demonstrated, theoretically, that these interactions may be accurately predicted using nonlinear methodologies. Also, various waste management scenarios may also be modelled to determine the most cost effective and environmentally acceptable technique of waste rock management.

Projected Output:

A coupled, nonlinear, simple, user-friendly model to predict with confidence acid drainage from waste rock dumps is the projected output of this project.

PREDICTION

Project 1.41.5: Guidelines for Characterisation of Waste Rock Piles
Budget: $25,000
Sponsor(s): To be determined
Manager: To be determined
Contractor: To be determined

Objectives:
To develop a template document or guideline that operators, regulators, and scientists can use to set up programs to characterize waste rock piles. The information collected can then be employed to further the understanding of the basic physics and chemistry of waste rock piles in general; and be used to develop tools for predicting the quality of seepage exiting these piles.

Fit With Program:
The short and long-term effects of acidic drainage, specifically from reactive waste rock at operational, non-operational and proposed mine sites is a serious concern. From both the industry and regulatory perspectives there is a need to accurately predict expected metal concentrations and loadings. The effluent and receiving water standards to which model outputs will be compared are stringent and this will require correspondingly high precision in developed predictive models. This level of modelling sophistication and precision may not be attainable with current knowledge of the physical and chemical behaviour of waste rock piles.

The development of useful predictive techniques for masses of acid generating waste rock depends on a thorough understanding of the basic principles involved, and many other factors including; mineral composition, size distribution, location, deposition method and history, climate etc. In addition, waste rock dumps have been used to dispose of other materials which may significantly affect the behaviour of the mass and it's effect on water quality in the surrounding region.

Projected Output:
A concise document that describes a template to develop work plans for characterizing waste rock piles including detailed field programs, data analysis, data interpretation and exact costs, and the second phase would complete the work.

PREDICTION

Project 1.62.1*: Freeze Control of Tailings - Site Characterization and Sampling
Budget: $60,000
Sponsor(s): To be determined
Manager: To be determined
Contractor: To be determined

Objectives:
The objective of this project would be to "map" the relationship between acidic drainage, tailings materials, and thermal conditions at a mine site and to collect samples for a laboratory program (1.61.2).

Fit with Program:
Implementation of reliable and economic control strategies for AMD are impeded by a lack of understanding of important cold weather processes and demonstrated performance. The development of freeze control strategies for mine tailings requires the collection and interpretation of basic field data from a site operating in a continuous permafrost zone. The influence of sulphide minerals and process chemicals on unfrozen water content, thaw degradation due to oxidation, reaction rates at low temperatures, and frozen hydraulic conductivity of saturated and unsaturated mine waste materials requires further study.

A current project (1.61.2) has identified numerous areas for further research and has proposed a field sampling and site characterization program to investigate these parameters further.

Projected Output:
A report detailing an active mine site from an acid generating perspective relative to the geothermal environment. Samples for a phase II laboratory program (1.62.2) would also be available.

* *Requires Management Committee approval.*

PREDICTION

Project 1.62.2*: Freeze Control of Tailings - Low Temperature Acid Drainage Laboratory Testing
Budget: $100,000
Sponsor(s): To be determined
Manager: To be determined
Contractor: To be determined

Objectives:
To conduct laboratory tests designed to assess and quantify the acid generating potential of tailings at low temperatures ($<5^{\circ}C$).

Fit with Program:
Prediction of acidic drainage for potential at northern mines is complicated because of the interpretation required to account for the climatic regime with extreme temperatures. Further research is needed for the development of reliable laboratory predictive methods for northern conditions and field evaluations are essential. Information on the acid generating potential and reaction rates of oxidation and neutralization reactions in sulphide bearing mine tailings needs to be acquired. The data would prove useful to provide guidance for the control of AMD from tailings using freeze control strategies. A better understanding of the behaviour of mine tailings at low temperatures would enable enhanced reliability of chemical and mathematical tools to predict the acid generating potential of mine tailings at low temperatures.

Projected Output:
The results of this program should provide design guidance for strategies involving freezing of mine tailings to control AMD.

* *Requires Management Committee approval.*

PREVENTION AND CONTROL ***Wet Barriers***

Project 2.15.3*: Laboratory Investigation on Oxidation from Resuspension in Water Covers

Budget:	$50,000
Sponsor(s):	To be determined
Manager:	To be determined
Contractor:	To be determined

Objective:
The objective of this laboratory project is to evaluate if additional oxidation results from the resuspension of the tailings particles in the water column.

Fit with Program:
The objective of ongoing project 2.18.1, Review and Documentation of Water Cover Applications, is to collect, collate and interpret information on water cover design and implementation of research projects in Canada and elsewhere and to identify gaps in the application of water cover technology. In the preliminary observations it was noted that no information has come to light on how resuspension affects the release rate of contaminants from tailings ponds, or how resuspension may effect the equilibrium between oxidizing and reducing processes.

A laboratory study is suggested where the additional oxidation obtained from resuspension is measured. Different tailings samples from various sites could be used. These will be resuspended in columns and the impact of resuspension measured (e.g. metal releases due to resuspension of the tailings particles). Different water cover depths could be used since it has been shown that oxygen concentration is not significantly dependent on water cover depth; the water cover is generally found to be saturated with oxygen except near the tailings/water interface.

Projected Output:
The main output will be a report which will improve the understanding of water covers. The information gathered during this project will provide valuable knowledge for industry and government on closure designs for water cover applications for the management of sulphidic tailings impoundments.

** Requires Technical and Management committees approval*

Project 2.18.1:	Review and Documentation of Water Cover Applications	
Budget:	$25,000	
Sponsors:Ontario		MOEE
		$10,000
	Ontario MNDM	$5,000
	Brunswick Mining & Smelting	$3,600
	CANMET	$5,000
Manager:	L. Surges, Brunswick Mining & Smelting	
Contractor:	University of Western Ontario	

Objective:
The objective is to collect, collate and interpret information on water cover design and implementation of research projects in Canada and elsewhere and to identify gaps in the application of water cover technology.

Fit with Program:
Many development projects and operating mines in Canada with an acid rock drainage (ARD) concern are proposing water covers for controlling acidic drainage from exposed surfaces and pits and underground workings, and from the large volumes of tailings and/or waste rock. This is because a water cover is considered the most effective of all the acidic drainage prevention and control measures. In spite of the enormous popularity and importance of water cover technology, there appears to be very little information in Canada on the water cover design parameters required to provide an adequate barrier to oxygen transport and hence the formation of acidic drainage. Several efforts have been initiated but the results of these have not been reported and are not readily available. As a result, it is not known what gaps in water cover technology readily exist. Much research has been completed and before additional work is carried out, MEND recommends a state-of-the-art literature review. This project will fill that void and propose additional research to help mining companies considering water covers as a close-out technology.

The following will be reviewed: Canadian and International mine sites (e.g. Boliden in Sweden, Norwegian Water Research Institute, U.S. Bureau of Mines) using water covers for managing acid rock drainage; and the ongoing MEND-sponsored water cover research (Project 2.15.1) at Noranda (Pointe-Claire) and CANMET (Elliot Lake). The review will focus on water cover studies and applications, and will not deal with underwater disposal (fresh tailings).

Projected Output:
The main output will be a report which will review the state-of-the-art for water cover applications for the management of sulphidic tailings; identify gaps that exist in water cover

technology; and make recommendations regarding the future direction of the wet barriers research area.

Project 2.21.4*:	Protocols for Engineered Soil Covers over Tailings and Waste Rock
Budget:	$30,000 to $50,000 (increase in scope)
Sponsor(s):	To be determined
Manager:	To be determined
Contractor:	To be determined

Objective:
The objective of this increase in scope is to include non-traditional soil and synthetic cover materials in the protocols or guidelines document for the design, construction and maintenance of engineered soil covers over sulphide tailings and waste rock.

Fit with Program:
The development of protocols will enable mine operators and regulators to assess the technical feasibility and cost of engineered soil covers and non-traditional soil and synthetic cover materials on a site specific basis; and will provide a sound basis for detailed engineering design and cost estimation, construction supervision and maintenance.

The development of the protocols follows the completion of the peer reviews (2.21.3a and 2.21.3b) and is expected to start in the summer of 1996. The peer review will ensure the quality and completeness of the field data and interpretations which will provide the basis for the protocols and will enhance the scientific credibility of several key project reports.

A literature review and the preparation of a database on alternate cover materials is underway (2.21.3b). Properties such as strength, flexibility, permeability, durability and the physical, chemical and biological processes which alter their performance with time will be included. This database will include test sites or case histories illustrating the use of these materials and is organized according to materials. This review and examination would be combined with a discussion of their potential for use in acid mine drainage cover applications and requirements for future research in this area.

Projected Output:
The protocols report is expected to be a dynamic type document to be distributed in loose leaf binder format so that the manual can be easily updated in the future . It will be a catalogue of state-of-the-art practices which will help identify gaps and will open doors to new ideas for future research projects.

** Requires Technical and Management committees approval*

PREVENTION AND CONTROL Dry Barriers

Project 2.22.3: Technical Economic Feasibility of Using Desulphurized Tailings for Covers

Budget: $150,000

Sponsor: .....Québec

.....$150,000

Manager: L. Bienvenu, Ministère des Ressources naturelles (MRN) du Québec

Contractor: Unité de recherche et de service en technologie minérale (URSTM)

Objective:

The objective of this project is to evaluate the use of desulphurized tailings as a component of multi-layered covers.

Fit with Program:

Pre-separation as a method to control acidic drainage was identified as a Priority I area in the MEND Revised Plan and again in the more recent Priority Setting exercise. If the sulphides can be separated from the non-sulphides, this opens up several disposal options, including the use of the non-acid generating portion in multilayered covers.

This project has some very interesting features including the use of tailings as the fine grained moisture retaining layer in composite covers. This would involve the separation of sulphides and possible metal recoveries to offset the cost of the covers. The low sulphide tailings would then be used for cover construction. The method seems to be economically attractive. The relationship between sulphide elimination and acidic generation will be evaluated.

Some minimal laboratory test work on the desulphurization of tailings will be completed. The efficiency of desulphurization will be verified in column testing. Using the NNP values over the percent sulphides was suggested to ensure larger application in the mining industry. An economic model will be established and refined and a laboratory protocol for using the technique developed.

Projected Output:

The final report will contain laboratory and computer methodologies for testing the efficiency of desulphurized tailings for possible use in covers.

Project 2.22.4*: Composite Cover using Tailings - Full Scale Site Monitoring
Budget: $150,000
Sponsor: Québec (MDA) $150,000
Manager: L. Bienvenu, Ministère des Ressources naturelles (MRN) du Québec
Contractors: Golder Associés/École Polytechnique

Objective:
The objective of this project is to monitor the performance of a large scale application of a multi-layered cover constructed with non-acid generating tailings.

Fit with Program:
The scientific review (2.21.3a) identified the need for large scale applications or case histories on the performance of soil covers to help in understanding the important parameters (e.g. climatic effects) related to soil covers. The result of full scale studies will be used for developing rational approaches for soil covers.

Les Terrains Aurifères (LTA) is owned by Barrick Gold Corporation and the site is located near Malartic in Northwest Québec. The mine was closed in 1965 and covers a disturbed area of about 140 hectares. The LTA tailings impoundment is located next to Malartic Goldfields (owned by the crown), a tailings site which is not acid-generating. Certain areas of the Malartic Goldfield tailings are overlain by LTA tailings. LTA was exploited during two distinct periods, the latter resulted in the deposition of acid generating tailings from the Bousquet complex (about 7.7Mt).

The closure option selected for the 60 hectare tailings site was the construction of a multilayer cover consisting of a 0.3m layer of locally available sand, a 0.8m layer of non-acid generating tailings from the Malartic Goldfields tailings impoundment and a 0.5m sand and gravel layer which will be seeded. The main objective of this soil cover is to minimize the influx of water and provide an oxygen diffusion barrier to minimize the influx of oxygen using a capillary barrier. The concept used for the construction of the cover was developed under 2.22.2b, "Evaluation of Dry Covers Built from Mine Tailings". The cover was constructed during the winter to allow for heavy machinery on site. It is proposed to instrument the site (oxygen diffusion, soil suction and moisture content) and monitor its performance over a three-year period.

Projected Output:
The final report will contain full scale monitoring results including construction methodologies and costs.

** Requires Technical and Management committees approval*

PREVENTION AND COTROL ***Dry Barriers***

Project 2.25.3: Assessment of Covers for Reducing Acid Generation from the Strathcona Tailings

Budget: $280,000 to $341,000 (increase in scope)

Sponsor: ..... Falconbridge

..... $61,000

Manager: G. Hall, Falconbridge

Contractors: Lakefield Research/Falconbridge

Objective:

The objective of this increase in scope is to complete detailed post-testing investigations on large scale lysimeters to have a better understanding of the relative effectiveness of the different measures in preventing and controlling sulphide oxidation and hence acid generation under controlled laboratory conditions.

Fit with Program:

The effectiveness of various organic materials (e.g. peat, municipal solid waste compost and lime-stabilized sewage sludge) and one contrasting non-organic (desulphurized tailings) material on eliminating or reducing acid generation and the movement of acidity and heavy metals from tailings ponds are being investigated and compared to control plots. Large quantities of organic material are now stockpiled and these materials may provide effective and affordable solutions to the rehabilitation of acid tailings.

Progress has been made on the characterization of the organic and non-organic materials, salt migration column tests and the pilot scale test cells (2.25.3, active). Additional work to complete the project was recommended. This includes the following tasks for the:

- Salt migration column test program (i.e. destructive core sampling of the columns for analyses, determining the upward water migration, additional chemical analyses on the lime stabilized sewage sludge, rate of evaporation)
- Pilot cell test program (i.e. direct gas measurements, literature review on carbon balance determination, destructive core sampling of the test cells, additional moisture content/suction data measurements, surface cracking investigation and methods to reduce the cracking).

Projected Output:

Collection of data to improve the understanding of the chemical and hydrological processes in the organic cover system will result. The final report will include an evaluation on the effectiveness of the potential benefits of using selected organic materials as covers for partially oxidized tailings.

PREVENTION AND CONTROL Dry Barriers

Project 2.25.4*:	Effectiveness of Paper Mill Sludges as Covers - Laboratory
Budget:	$50,000
Sponsor(s):	To be determined
Manager:	To be determined
Contractor:	Competitive bidding

Objective:
The objective of this project is to determine the effectiveness of paper mill sludges as cover materials in preventing and controlling sulphide oxidation and hence acid generation under controlled laboratory conditions.

Fit with Program:
Paper mill sludges were given a high priority for future research in the study evaluating potential barrier materials (2.20.1). This evaluation was based on a two-stage screening process which takes technical aspects, cost, environmental and practical application into consideration. Paper mill sludges were considered to be a potential barrier material providing broadly based (country wide) benefits and good likelihood for success. Paper mill sludges do offer potential cost savings due to the proximity of forest products industry operations to some mine sites (Northeast Ontario/Northwest Quebec). The committee recommended during the Priority Setting that future dry barriers research be carried out on high priority materials.

The primary function of this cover material is the reduction of the ambient oxygen concentration at the tailings/cover interface by consumption of oxygen. The project will involve the chemical and physical characterization of the potential cover material as well as laboratory scale simulations of tailings areas with and without cover material. The results will be compared to other organic materials presently being evaluated under 2.25.3. These include peat, municipal solid waste compost and lime-stabilized sewage sludge.

Projected Output:
Collection of data to improve the understanding of the chemical and hydrological processes in the organic cover (paper mill sludges) system will result. The study is focussing on an alternative material not researched before by MEND and may provide effective and affordable solutions to the reclamation of sulphitic tailings.

** Requires Technical and Management committees approval*

Project 2.30.1*:	Waste Rock Prevention and Control Guidelines
Budget:	$30,000
Sponsor(s):	To be determined
Manager:	To be determined
Contractor:	To be determined

Objective:
The objective of this project is to produce a document that lists guidelines for the various waste rock prevention and control technologies. Guidelines will include performance and operational constraints, materials characterization, design requirements, performance monitoring needs, and site specific features of importance.

Fit with Program:
Although some of the prevention and control techniques available for tailings may be applicable to waste rock, the constraints and procedures are different. Waste rock is much less homogeneous than tailings and much more permeable. Consequently waste rock piles have the potential to develope induced air flows due to temperature gradients and porosity. Also, the potential for differential settlement in the piles may be greater in waste rock than in tailings.

The development of guidelines for prevention and control technologies applicable to waste rock will provide an easy to understand synopsis of the experience gained from a large number of waste rock projects. This will enable mine operators and regulators to assess the technical feasibility of the various technologies on a site specific basis and will provide a sound basis for detailed engineering design and cost estimation, performance monitoring and maintenance. These generic guidelines will be developed from a wide range of site specific experience.

Projected Output:
The deliverable for this project will be a set of guidelines for the toolbox of technologies applicable to the prevention and control of waste rock ARD.

** Requires Technical and Management committees approval*

TREATMENT

Project: 3.42.3 Disposal of Lime Treatment Sludge
Budget: $150,000
Sponsors: ..... CANMET
$50,000
Manager: To be determined
Contractor: To be determined

Objectives:
To evaluate and document methodology for the long term stabilization, disposal and if possible potential beneficial use of lime treatment sludge.

Fit With Program:
Lime neutralization will be the principal method for treating acidic water for the foreseeable future; and this activity represents a large proportion of the liability of acid generating mine wastes. Although lime treatment technology is well developed, a good understanding of the best methods for sludge stabilization and disposal under a wide range of conditions is not well developed or documented.

The principal concerns about the treatment sludge are the volume occupied and the long-term chemical stability of the sludge, particularly with respect to mobilization of heavy metals that have been coprecipitated with gypsum, and aluminum and iron hydroxides, and the decommissioning of sludge disposal areas.

This project will complement the MEND project (3.42.2) examining the characterization and stabilization of AMD treatment sludges and will focus on gathering information, analyzing field practices, costing, engineering. Some laboratory studies will be required. Physical and chemical methods for preventing the mobilization of heavy metals in the long term (100's of years) will have been investigated in project 3.42.2.

Possible uses of lime sludge such as to create low permeability capping material, underground backfill or recycling to smelter will be reviewed. Other use possibilities will be investigated, taking account of the experience at mine sites in Canada and internationally. Incorporation of the sludge in paste backfill or tailing is a good possibility during mine operations.

Projected Outputs:
This project will complete the Treatment component of the MEND program, and will form an important part of the "MEND Manual". With the documentation produced from this project, operators and designers of lime treatment plants will more precisely be able to plan for long term treatment strategies.

Project 5.1.2: Workshops
Budget: $40,000
Sponsor: ..... CANMET
$10,000
Manager: MEND Secretariat
Contractor: Ken Wheeland

Objectives:
To present workshops on completed topics of the MEND program across Canada.

Rationale and Fit With Program:
Since November 1993, there have been eight workshops presented at five sites (Val D'Or, Sudbury, Vancouver, Montréal and Sydney). At each workshop there were 50-80 participants from industry, government, consulting firms, research and environmental groups. The major themes presented and discussed to date are: chemical treatment; economic evaluations; AMD technology for coal metal mines predictions and modelling; and, in-pit disposal. These workshops were well received and both the contractors who were representing their work and the participants found the workshops useful. Also useful feedback received from participants used to refine/focus remaining program.

The following topics are proposed for 1996:

Topic	Possible Presenter(s)	Possible Location, Date
General MEND	Orava, Pettit, Lapakko, MEND	Winnipeg, March 1996
Dry Cover Technologies	Barbour, Yanful, Arlotte	Sudbury, April 1996
Monitoring	Various	Saskatoon, June 1996
MEND Ontario	Various	Sudbury, Oct. 1996
Dry Covers - NEDEM	Various	Rouyn-Noranda, Oct. 1996
Prediction	Various	Vancouver, Nov. 1996

Workshops will be held between now and the 1997 Conference on a selective basis and will provide an opportunity to fine tune the short course material that will be presented at the 4th ICARD in Vancouver.

TECHNOLOGY TRANSFER

Project 5.7.2	CD ROM Publication
Budget:	$40,000 (Reduction from $80,000, 1995)
Sponsor(s):	To be determined
Manager:	MEND Secretariat
Contractor:	In-house

Objective:
To assemble a library of MEND documentation on a single, searchable compact disc.

Rationale and Fit With Program:
The increasing mountain of information generated by MEND and others on the subject of acidic drainage is truly overwhelming. One very efficient way to have all of the generated information in one location **and** accessible is to have all of the MEND reports on a single CD ROM disc.

A CD ROM disc with search software attached allows anyone with a CD drive to search any subject or topic, and to produce relevant "hard" paper copies if desired.

Unfortunately, a large proportion of MEND reports completed to date are in a variety of formats and computer codes, and in many cases a computer version of the report does not exist. Also, most recent reports have multi-colour illustrations.

The $40,000 cost is an estimate to scan all past MEND reports and to prepare the compact disc encyclopedia. The work would start in 1996 and will be complete in 1997. This disc will be offered for sale at a nominal cost. By having the disc available, users could obtain a copy of over 100 MEND reports for less than the cost of a single hard copy of a MEND report.

The Technology Transfer committee will monitor carefully the CD ROM technology development over the next year, to ensure that the technology selected will not be obsolete in the near future.

TECHNOLOGY TRANSFER

Project 5.8.1: Preparation of an Educational Program for Grade School Teachers to Accompany the MEND Video

Budget:	$5,000
Sponsor(s):	To be determined
Manager:	B. Downing, Teck Exploration
Contractor:	Don Stevens

Objectives:
To prepare a simple AMD course for grade school teachers to accompany the short version of the MEND video and to compliment similar resource units which have been developed by teachers with funding/participation from the B.C. Mining Association.

Rationale and Fit With Program:
MEND videos have been prepared and are available to the public. These videos are very topic specific and may not have a desirable impact on students at the grade school and high school levels. It is recommended to build resource units for teachers at these levels to accompany the MEND videos. The resource units would provide the necessary background information and tools to effectively educate students on acidic drainage in Canada. Other such resource units have been used in many schools in B.C. and other provinces are adapting these units into their curriculum. While the resource units are free to teachers, each teacher is required to attend a half-day workshop before receiving the resource unit.

Don Stevens, a grade 10 teacher in B.C., has completed the grade 10 and 11 resource unit and is now preparing a teaching unit on mining and acidic drainage. Slides and supplemental information on acidic drainage have been made available by the B.C. mining community and are being used to assemble the resource unit. Additional funding is required to: create teaching slides and material; create laboratory projects on acidic drainage; and fund workshops to present the material to the teachers.

British Columbia will serve as the pilot study but the objective is to expand this program across Canada and into northern regions.

PREDICTION/PRÉVISION

1.11.1 Critical Literature Review of Acid Drainage from Waste Rock, April 1991. $25

1.15.2a MINEWALL 2.0 User's Manual, September 1995. $30

1.15.2b MINEWALL 2.0 - Literature Review and Conceptual Models, September 1995. $25

1.15.2c Application of MINEWALL 2.0 to Three Minesites, September 1995. $25

1.16.1a Investigation of Prediction Techniques for Acid Mine Drainage, November 1989. $25

1.16.1b Acid Rock Drainage Prediction Manual, March 1991. $40

1.16.1c New Methods for Determination of Key Mineral Species in Acid Generation Prediction by Acid-Base Accounting, April 1991. $25

1.17.1a Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec- 1985 Program, July 1986. $25

1.17.1b Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 2 - 1986 Program, July 1987. $25

1.17.1c Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 3 - 1987 Program, Volume I Report, May 1988. $25

Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 3 - 1987 Program, Volume II - Appendices, March 1988. $25

Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 3 - 1987 Program, Supplementary Report, March 1989. $25

1.17.1d Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, "Generation and Evolution of Acidic Pore Waters at the Waite Amulet Tailings - Final Report", April 1990. $60

1.19.1 Long Term Acid Generation Studies: Cinola Project British Columbia (includes diskette), March 1994. $35

1.19.2 Scaling Analysis of Acid Rock Drainage, December 1995. $25

1.21.1a Critical Review of the Reactive Acid Tailings Assessment Program (RATAP.BMT2), April 1990. $30

1.21.1b Workshop on Modelling of Reactive Tailings Sponsored by the MEND Prediction Committee, Final Report, August 1990. $40

MEND Reports Available Continued...

1.22.1a Field Procedures Manual: Gas Transfer Measurements Waste Rock Piles Heath Steele Mines New Brunswick, March 1994. $30

1.25.1 Soilcover Users Manual Version 1.0 (includes diskettes), March 1994. $40

1.32.1 Prediction and Prevention of Acid Rock Drainage from a Geological and Mineralogical Perspective, October 1993. $35

1.42.1 Critical Review of Geochemical Processes and Geochemical Models Adaptable for Prediction of Acidic Drainage from Waste Rock, April 1995. $30

1.51.1 Quantitative Analysis of Chemical and Biological Kinetics for the Acid Mine Drainage Problem, June 1994. $30

1.51.2 Nonlinear Modelling of Chemical Kinetics for the Acid Mine Drainage Problem and Related Physical Topics, October 1993. $25

PREVENTION AND CONTROL/PRÉVENTION ET CONTRÔLE

2.11.1a Subaqueous Disposal of Reactive Mine Wastes: An Overview, June 1989. $25

A Preliminary Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia, March 1990. $25

A Preliminary Assessment of Subaqueous Tailings Disposal in Anderson Lake, Manitoba, March 1990. $25

A Preliminary Assessment of Subaqueous Tailings Disposal in Mandy Lake, Manitoba, March 1990. $25

Geochemical Assessment of Subaqueous Tailings Disposal in Buttle Lake, British Columbia, March 1990. $25

2.11.1b Geochemical Assessment of Subaqueous Tailings Disposal in Anderson Lake, Snow Lake Area, Manitoba, September 1990. $25

Geochemical Assessment of Subaqueous Tailings Disposal in Mandy Lake, Flin Flon Area, Manitoba, September 1990. $25

2.11.1c A Preliminary Biological and Geological Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia, March 1991. $25

Chemical Diagenesis of Submerged Mine Tailings in Benson Lake and Natural Sediments in Keogh Lake, Vancouver Island, British Columbia, June 1992. $25

2.11.1d A Critical Review of MEND Studies Conducted to 1991 on Subaqueous Disposal of Tailings, July 1992. $25

2.11.2a Literature Review Report: Possible Means of Evaluating the Biological Effects of Sub-Aqueous Disposal of Mine Tailings, March 1993. $25

2.13.2a Expérimentation de l'inondation du parc à résidus miniers - Solbec Cupra (Phase IV). Rapport Sommaire, Décembre 1993. $35

2.13.2b Flooding of a Mine Tailings Site - Solbec Cupra. Suspension of Solids: Impact and Prevention, March 1994. $25

2.13.2c Inondation artificielle du parc à résidus miniers Solbec Cupra: Études microbiologique et chimique - Rapport final, Mars 1994. $35

2.20.1 Evaluation of Alternate Dry Covers for the Inhibition of Acid Mine Drainage from Tailings, March 1994. $30

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